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CONTRIBUTIONS TO OCEANOGRAPHY AND FISHERIES BIOLOGY
BYDRAES TOT OSEANOGRAFIE EN VISSERYBIOLOGIE

CAPE TOWN KAAPSTAD

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DISTRIBUTION, AVAILABILITY AND MOVEMENTS OF PILCHARD *SARDINOPS OCELLATA* OFF SOUTH AFRICA, 1964 — 1976

R. J. M. CRAWFORD

Pilchards *Sardinops ocellata* in South African waters shoal according to size. Between the periods 1950-1954 and 1975/76 age at maturity decreased, probably because a reduced age structure for the population resulted from the introduction of small-meshed (12,7-mm) nets. Commercial purse-seine catches have been recorded from the Orange River to Cape Infanta, the majority inside the 200-m bottom contour. The species exhibits age-specific patterns of availability and distribution, both of which are related to environmental conditions. Eggs are spawned in warm water that promotes rapid development. The densest concentrations occur during spring and summer, the main upwelling seasons, thus ensuring an abundant food supply for developing larvae and juveniles. Initial recruitment of nought-year-old fish is heaviest along the West Coast, where in winter the plankton standing stock is highest. Upwelling begins in spring and many young pilchards then move southwards into newly productive waters. Recently mature fish occupy the southern fishing areas, where warm Agulhas water is found, during spring and summer, then from April or May migrate in an easterly direction past Cape Agulhas. Further east they appear to be found in midwater, feeding in the chlorophyll-maximum layer. Older pilchards historically occurred off the West Coast, feeding in nearshore waters in autumn and winter, but moving to warmer off-shore water to spawn in spring and summer. A severe decline in egg abundance in the St Helena Bay vicinity has coincided with a greatly reduced contribution by these older age groups to the commercial landings.

Sardyn *Sardinops ocellata* in Suid-Afrikaanse waters skool saam na gelang van grootte. Tussen die tydperke 1950-1954 en 1975/76 het die ouderdom by bereiking van geslagsrypheid gedaal, moontlik omdat 'n verlaagde ouderdomstruktuur vir die bevolking deur die ingebruikstelling van fynmaasnette (12,7 mm) veroorsaak is. Handelsvangste met beursnette is opgeteken van die Oranjerivier af tot by Kaap Infanta, meesal binne die bodemkontoer van 200 m. Die spesie openbaar patrone, spesifiek volgens ouderdomsgroepe, van beskikbaarheid en verspreiding, wat met omgewingstoestande verband hou. Eiers word uitgestort in warm water wat ontwikkeling versnel. Deurdat die digste konsentrasies in die lente en somer, die vernaamste opwellingseisoene, voorkom, is die groeiende larwes en jongvis van volop voedsel verseker. Aanvanklike rekrutering van nul jaar oue vis is die intensiefste langs die Weskus, waar die planktonbiomassa in die winter die grootste is. Opwelling begin in die lente, en dan trek baie jongsardyn suidwaarts na pas produktiewe waters. Vis wat onlangs geslagsrypheid bereik het, beset die suidelike visgebiede, waar warm Agulhas-water te vind is, gedurende die lente en somer. Van April of Mei af migreer hulle ooswaarts verby Kaap Agulhas. Verder oos word hulle skynbaar in midwater aangetref en wei in die chlorofilmaksimum-laag. Ouer sardyn het voorheen langs die Weskus voorgekom en in die herfs en winter in aanlandige waters gewei, maar in die lente en somer na warmer aflandige waters beweeg om kuit te skiet. 'n Drastiese daling in die talrykheid van eiers in die omgewing van St Helenabaai het saamgeval met 'n skerp daling in die bydrae van hierdie ouer jaarklasse tot die handelsvangste.

Previous investigations into the distribution and movements of pilchard *Sardinops ocellata* in South African waters have been conducted by Davies (1956b), Baird (1970, 1971) and Heydorn *et al.* (1978). However, these studies concentrated on particular categories of the pilchard population only, whereas it is the purpose in this report, through analysis of catch statistics collected between 1964 and 1976, to consider the patterns of distribution and availability exhibited by each of the major age-structured components of the stock, and to document these in such a manner that they may be incorporated in future simulation models of the fishery.

Commercial purse-seine fishing for pilchard was initiated in 1943 in the St Helena Bay area (Fig. 1) under the stimulus of a war-time demand for canned fish. Although no accurate records were kept, the catch of pilchard during that season was estimated at 3 900 metric tons. Over the next few years the industry expanded rapidly, and by 1949 the quantity landed had risen to some 68 000 tons (Du Plessis 1959). This expansion prompted the introduction of certain control measures which have since come to include restrictions on the number and capacity of processing plants and vessels, limitation of the maximum allowable catch and duration of the fishing season, and enforcement of a minimum mesh size (Du Plessis *op. cit.*, Stander and Le Roux 1968, Gertenbach 1973, Newman and Crawford 1980, Crawford 1981).

It is apparent from annual landing figures

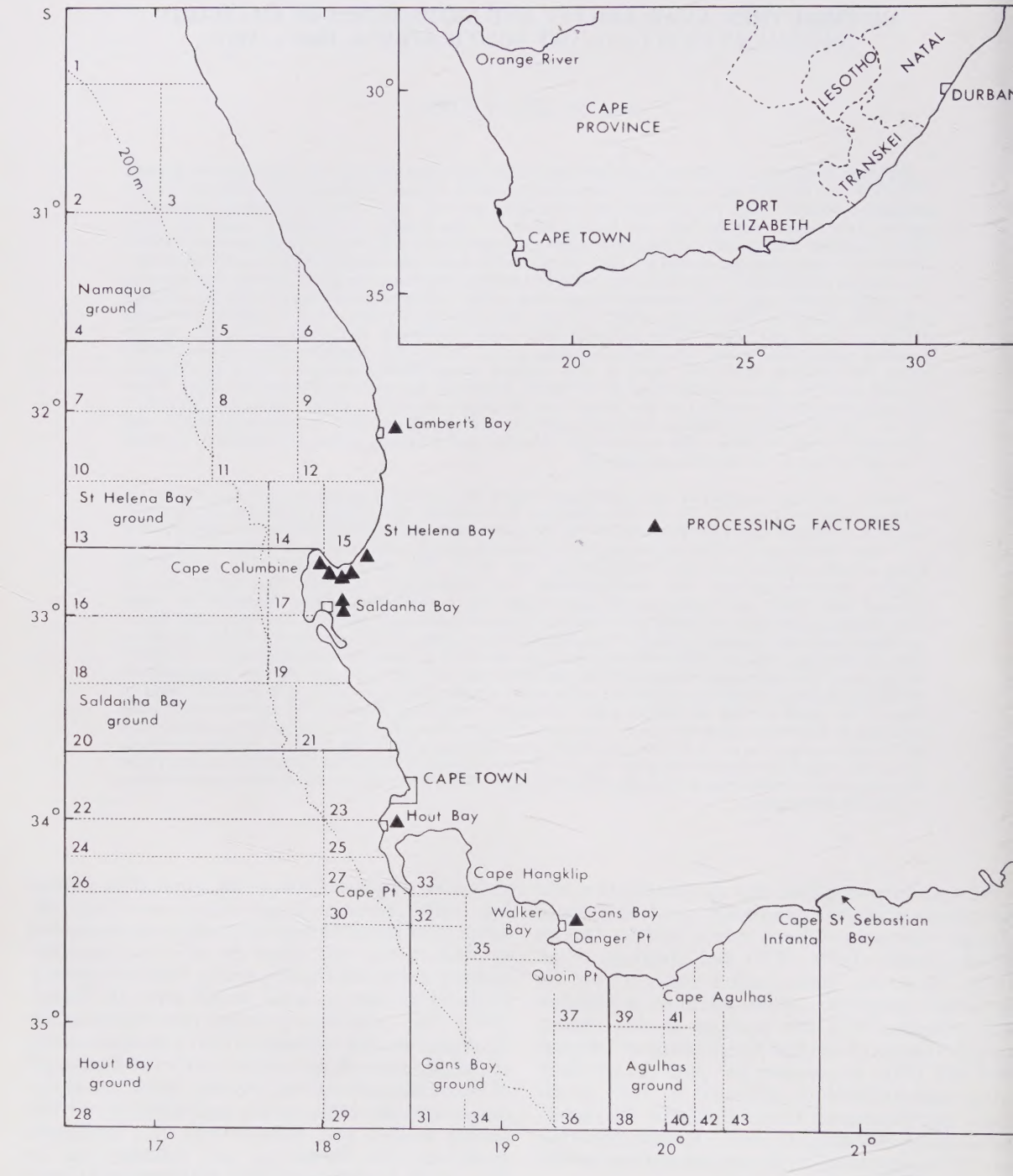

Fig. 1: The 43 areas used to delimit the distribution of pilchard shoals, showing the major fishing grounds an locations of the processing factories operative in 1976 — area 1 and the Namaqua ground extend north to the Orange River (inset)

Table I: Landings of pilchard and their contribution to the total South African purse-seine catch, 1950-1976

Year	Landings (metric tons)	Proportion of total combined landings (%)
1950	85 317	63,1
1951	101 879	50,8
1952	170 032	62,4
1953	132 481	60,9
1954	88 303	41,9
1955	121 949	55,2
1956	76 589	49,4
1957	109 475	54,3
1958	194 390	71,1
1959	260 210	82,6
1960	318 030	77,2
1961	402 192	81,9
1962	410 159	82,5
1963	390 129	91,4
1964	256 096	60,2
1965	204 481	42,6
1966	118 031	33,1
1967	69 651	13,7
1968	107 777	29,2
1969	56 057	15,9
1970	61 808	17,2
1971	87 628	27,0
1972	104 153	24,0
1973	68 982	15,5
1974	15 977	4,0
1975	89 182	21,9
1976	176 434	43,3

Table I) that the performance of the pilchard stock has been dominated by the exceptionally large catches which were recorded during the late fifties and early sixties. These have been attributed to strong recruitment experienced between 1956 and 1959 (Newman and Crawford 1980). The increased abundance of pilchard in these years led to considerably more fishing effort, of which much was later diverted to anchovy *Engraulis capensis* and other resources through the introduction of a small-meshed (12,7-mm) net.

After 1966, anchovy displaced pilchard as the main contributor to the commercial landings, but the pilchard remains an important component of the multi-species fishery as evidenced by both the large catch of 176 000 tons recorded in 1976 and the considerable influence exerted by pilchard availability on overall catch rates (Crawford 1981).

DISTRIBUTION OF COMMERCIAL PURSE-SEINE CATCHES

Statistics submitted by the skippers of purse-seine vessels were reasonably comprehensive for the period 1964 — 1976 (Crawford *et al.* 1978). These statistics were used to determine monthly distribution patterns for commercial catches and as such are illustrated in chart form in the Appendix. The geographical location of shoals was delimited by dividing the fishing region into 43 longshore and off-shore areas (Fig. 1) and noting the incidence of pilchard catches in each. In certain instances, especially when effort was deployed at the northern or eastern extremities, further clarification was obtained by plotting actual catch positions.

Catch rates are given in order to illustrate spatial variations in the density of fish. These were derived from catch (Crawford *et al.* 1978) and effort (Crawford 1981) estimates for 20 somewhat larger areas, formed by regrouping the original 43. The catch-per-unit-effort levels are expected to be influenced to a certain degree by variations in the availability of other species but, within the four broad categories chosen (<10, 10-25, 25-50 and >50 metric tons per standard-boat-day), they should nevertheless provide a fair measure of abundance. It should be noted that, although the 1964 and 1965 seasons were closed for pilchard fishing from August to December inclusive, limited quantities of pilchard were sometimes caught in these months as a result of fishing aimed at the anchovy resource. These catches have been included on the charts, but catch rates are likely to be unrealistically low because skippers endeavoured to avoid pilchard. To assist in interpretation of the results, areas in which no fishing was conducted are also shown.

Pelagic fish often shoal by size, examples being *Sardina pilchardus* (Mužinić 1977), *Sardinella aurita* (Ben-Tuvia 1960) and *Scomber scombrus* (Sette 1950). A likely reason for this form of segregation is that small fish would find it difficult, in terms of energy requirements, to keep pace with larger individuals (Mužinić *op.cit.*). The normal size range encountered in shoals of pilchard in South African waters was examined by investigating the length distributions of fish from 310 purse-seine catches made between 1974 and 1976. The results demonstrate that fish in any one shoal seldom vary in caudal length by more than 5,5 — 6,0 cm (Fig. 2). Because of this fact, the modal length of fish caught in known areas, whenever available from field observations, has been given on the distribution charts to give some idea of geographical and seasonal variations in the size of pilchard encountered. Ages may be inferred from age-length keys (Crawford *et al.* 1978).

Davies (1956a) examined the gonad activity of 1 872 pilchard collected between 1950 and 1954 during the main spawning season (September — February). His information suggests that no fish

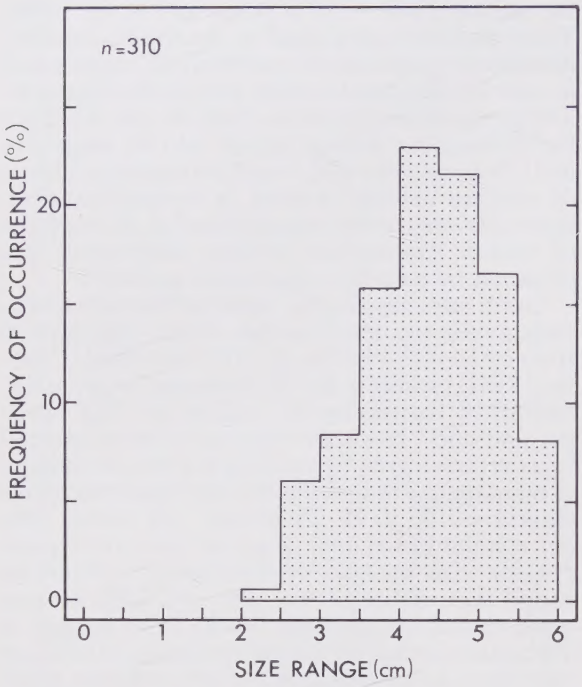

Fig. 2: Frequency of occurrence of size ranges (caudal length) of pilchard sampled from individual commercial purse-seine catches

were mature before four years of age, that 50 per cent were reproductively active at five years and that all six-year-olds were capable of spawning.

Analysis of 2 374 fish sampled during the 1975/76 spawning season, however, provided significantly different results, indicating that fish were maturing at a much earlier age. Some one-year-olds, 50 per cent of the two-year-olds and all four-year-olds proved to be reproductively active. This change may well have been caused by the considerably reduced age structure which resulted from a lowering of the minimum mesh size for nets from 32 to 12,7 mm over the period 1963 — 1965 (Crawford *et al.* 1978, and Fig. 3). For charting purposes, fish less than one year old were considered to be juveniles and have been illustrated in different shading from that used for all older age groups. Thus the distribution of recruit year-classes has been highlighted.

The results (see Appendix) show that the great majority of pilchard catches are made inside the 200-m bottom contour, except in the vicinities of Cape Columbine and Cape Point where this isobath approaches the mainland. This pattern could be influenced to some extent by the preference of skippers to remain within sight of the coast. Mo of the catches recorded further off shore wer made on the northern grounds. Examples wer the nought-year-old fish north-west of the Olifan River in February and May 1967 and Januar 1968, west of the Olifants River in February an June 1971 and north-west of Cape Columbine i February and April 1968 and May and June 196 the one-year-old fish north-west of and west of th Olifants River in March 1971 and February 197 respectively; and the four-year-old fish west of th Olifants River in January 1972 and west of Saldanh in January 1964 and January, February and Apr 1966. However, catches of this last age class wer also made well south of Walker Bay in April 1970

Commercial catches of pilchard have bee recorded as far north as the Orange River (nought year-olds in March and June 1971; five-year-old in July 1964, May, June, July and August 1966; six year-olds in April 1966) and as far east as Cap Infanta (nought-year-olds in January 1970; one year-olds in January 1970 and June 1975; two year-olds in May 1976; three-year-olds in Jun 1965, March 1972, March 1973, February, March and April 1976; four-year-olds in January 197 and February 1974; five-year-olds in April 1967) However, although the species may be found continuously along the South African coastlin between the Orange River and Cape Infanta, there is no evidence as yet of sizable quantities of pilchar between one and four years old in the extrem north or of six-year-olds off Cape Infanta. Furthe east, pilchard have been recorded in the stomach of hake *Merluccius* sp. trawled off Port Elizabeth (Hecht 1976) and the species also occurs regularly off the coasts of Transkei and Natal (Fig. 1) each winter (Davies 1956b). Baird (1971) notes tha nought-, five- and six-year-olds are virtually absen from these latter shoals and that one-year-olds are also encountered only infrequently (Table II). More

Table II: Frequency-at-age of pilchard collected in Natal 1955 — 1969 (after Baird 1971)

Year	Frequency at age (%)						
	0	I	II	III	IV	V	VI
1955	—	5,4	46,6	44,1	3,0	0,9	—
1958	—	1,9	62,9	29,7	4,8	—	—
1962	—	2,3	25,6	7,2	56,6	8,2	—
1963	—	2,3	40,0	46,5	11,2	—	—
1964	—	—	40,1	38,4	21,4	—	—
1965	—	16,7	56,5	25,3	1,4	—	—
1968	—	7,6	31,1	48,5	12,7	—	—
1969	—	0,5	34,1	45,8	17,9	0,9	0,7

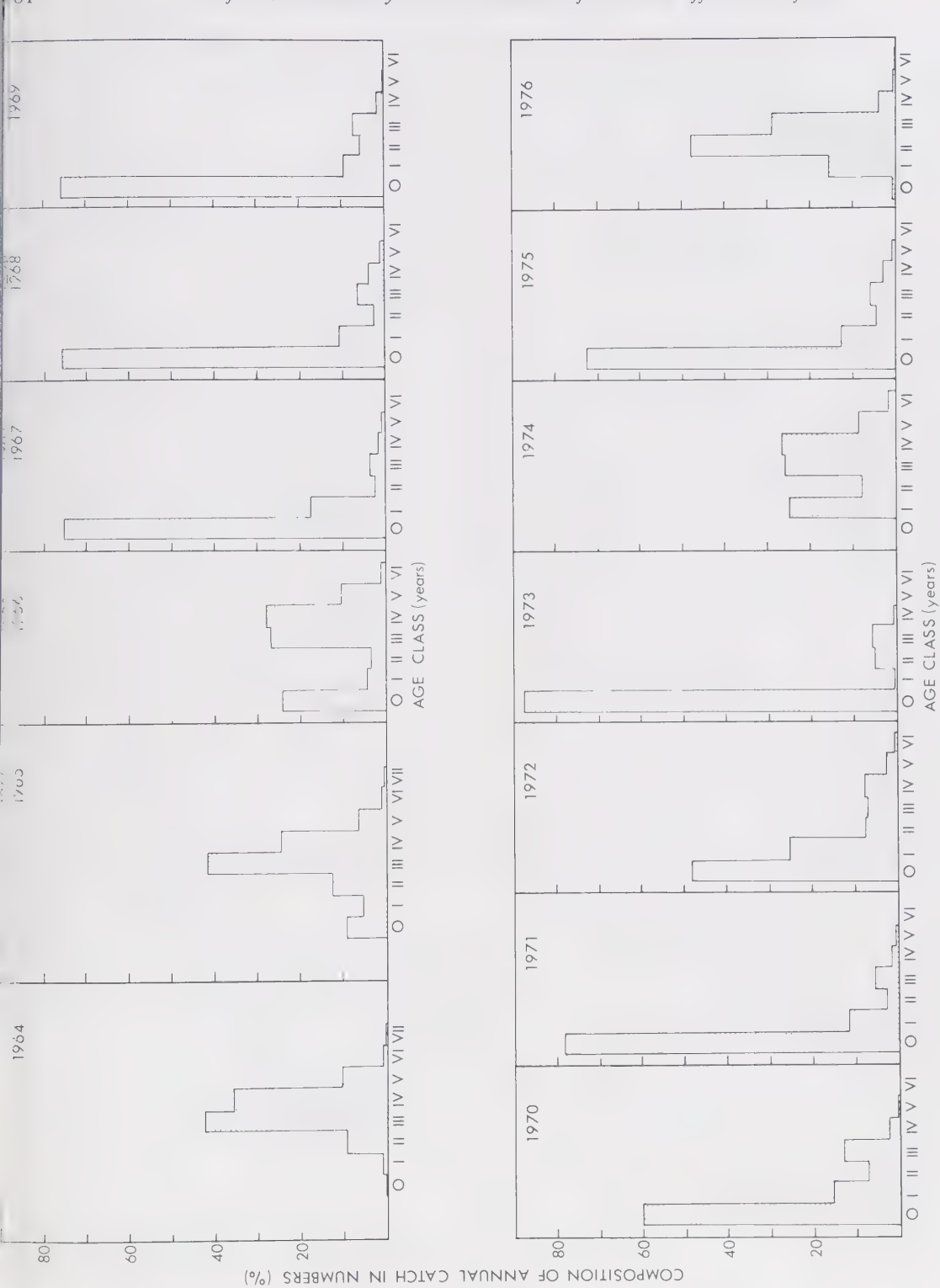

Fig. 3: Age composition of South African pilchard landings, 1964-1976 (data after Crawford *et al.* [1978])

recently (in 1974), however, fish with a caudal length of 6,0 — 9,5 cm (presumably nought-year-olds) have been washed ashore in Natal (Heydorn *et al.* 1978), but this is an isolated instance and such pilchard may be regarded as scarce off Natal. Pilchard spawning has been recorded off Port Elizabeth and East London (Anders 1975).

AVAILABILITY, ABUNDANCE AND MOVEMENTS

In order to quantify seasonal patterns of availability and distribution, the 43 areas were combined into six fishing grounds (Fig. 1) chosen to correspond with the major environmental regions of the South-Western Cape (Crawford *et al.* 1980). As illustrated in the Appendix, the seaward extension of these grounds is seldom greater than 50 km and they are therefore of approximately equal size, except for the extensive but relatively lightly exploited Namaqua area.

Monthly levels of catch per unit effort on each of the six grounds were calculated for the different age components of the pilchard stock. In this process each catch was allocated *in toto* to a particular age class by comparing the modal age of fish sampled with the corresponding age-length key (Crawford *et al.* 1978). Thus non-dominant age classes were ignored, but because two- to four-year-old fish and the older pilchards are considered here as groups, the effect is not expected to undermine the purposes of this report.

Monthly indices of availability were derived by summing over all grounds the mean catch rates for the month under consideration during the thirteen-year period (1964 — 1976). Estimates of the relative abundance of fish that could, as a rule, be expected to be present on each of the six fishing grounds during any particular month were established in a similar manner (the summation over grounds being omitted). Catches of nought- and one-year-olds were minimal in 1964 and 1965 when fishing with the small-meshed (12,7-mm) net was restricted to the anchovy population. Therefore, only the period 1966 — 1976 was considered for these groups. Also no values were calculated for October, November or December for any age class, fishing in these months being prohibited after 1965.

The resulting indices, expressed as percentages of the maxima, appear in Figures 4 and 5. Patterns for fully recruited age groups (all groups except nought-year-olds in Figures 4 and 5) are probably

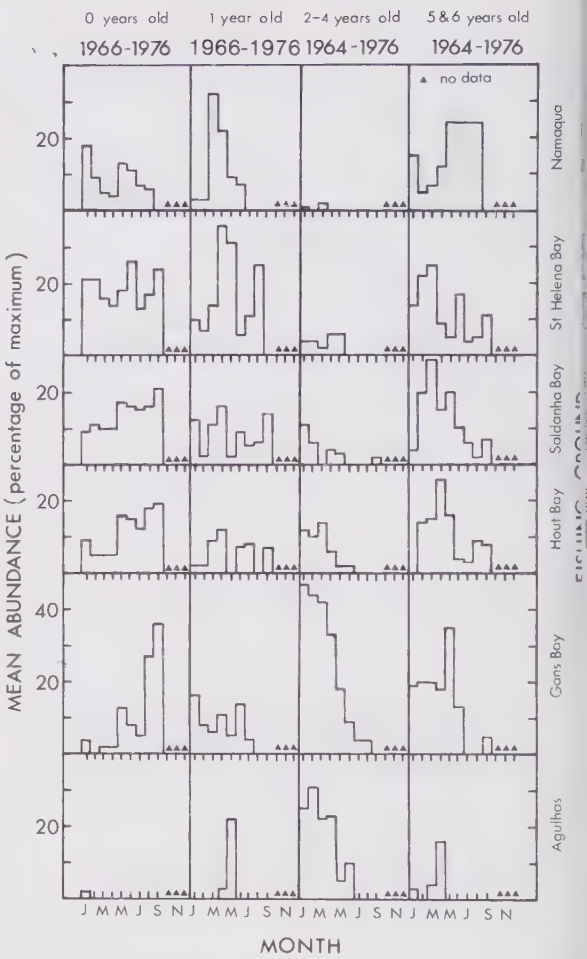

Fig. 4: Age-specific monthly abundance indices for pilchard for six fishing grounds

determined to a certain extent by mortality, and especially by fishing mortality, with catch rates falling as the season progresses. However, unrealistically high values of total mortality (Z = 3,8, 5,9 and 3,3 for one-year-olds, two- to four-year-olds, and five- and six-year-olds respectively) would be required to produce the observed declines in availability. Newman (1970a) demonstrated that the natural mortality coefficient for pilchard in South West African waters during the period 1963 — 1966 was less than 0,59, whereas estimates of fishing mortality in South Africa for the period 1964—1976 have ranged between 0,01 and 0,79 with a mean of 0,42 (Centurier-Harris *et al.* 1977). Undoubtedly, therefore, movements of fish shoals

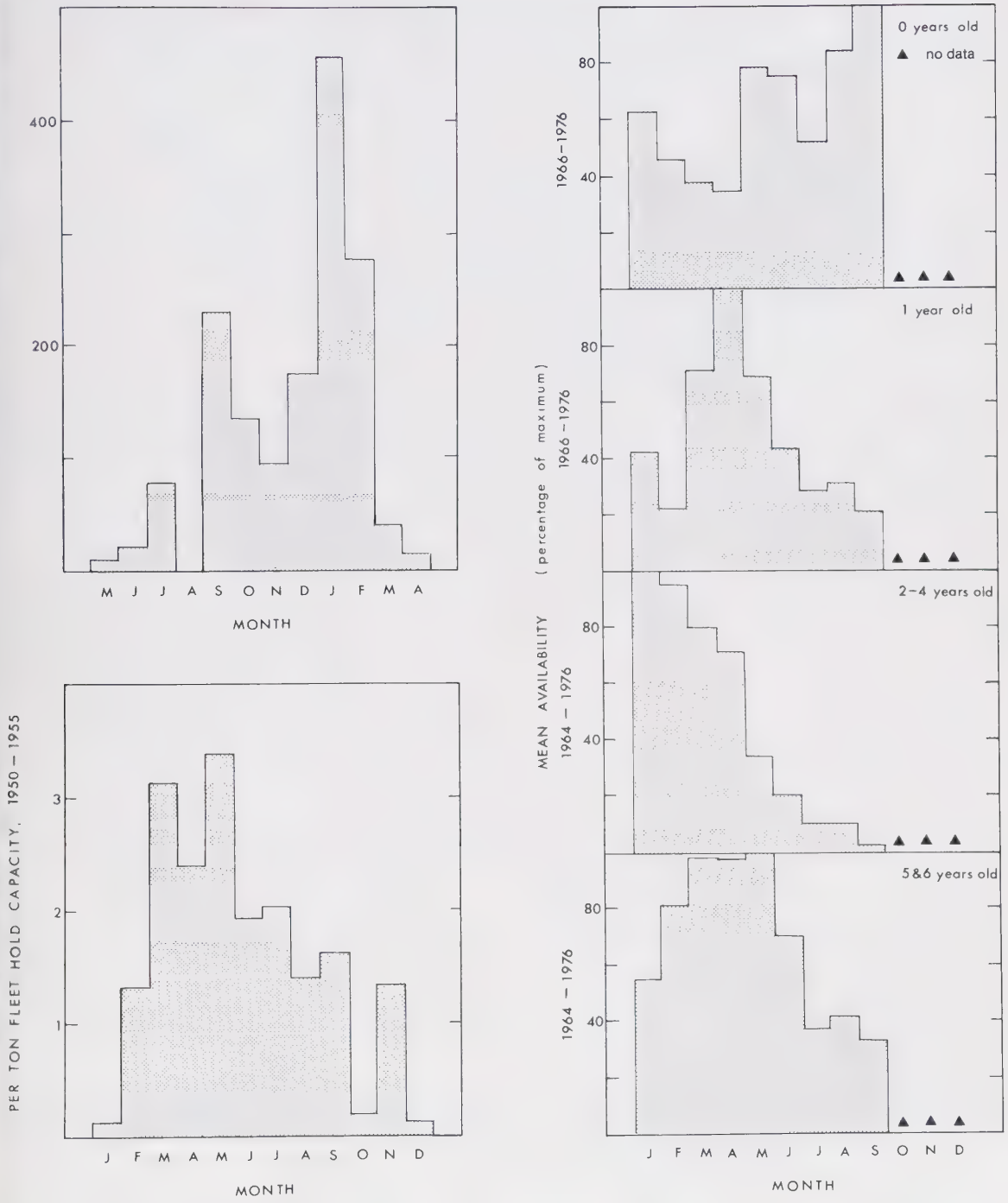

Fig. 5: Monthly egg production and availability indices for pilchard off South Africa

also exert a considerable influence, and they will be discussed in greater detail when considering the various age components of the population.

Spawning

Both migrations and seasonal trends in availability may be expected to be closely related to reproductive behaviour. The pilchard is a serial spawner (O'Toole 1977) and surface plankton tows, conducted on a regular basis between 1951 and 1967 (A.S. Anders, Sea Fisheries Institute, unpublished manuscript), have demonstrated that in South African waters most of the spawning takes place between September and February (Fig. 5). Figure 6 shows the surface distribution of pilchard eggs in South African waters during the spawning seasons between 1963 and 1966/67.

Eggs were initially most abundant off shore in the vicinity of St Helena Bay, but the intensity of spawning in this region later declined and yields during the two years from spring 1965 onwards became negligible (Fig. 6). Large concentrations were also encountered between Cape Point and St Sebastian Bay though here, unlike in the northern area, there was no apparent decrease in spawning.

Nought-year-old fish

There is a sharp rise in the availability of nought-year-old pilchard during May, and from then until September they are generally caught in large numbers (Fig. 5). A close similarity between the pattern in these months and the egg abundance indices for September — January suggests that young pilchard recruit to the fishery approximately eight months after being spawned. Between October and December there are no adequate data on the availability of this age group, but the moderately high level found for January suggests that it remains fairly high. Thereafter a steady decrease is apparent, catch rates reaching a minimum in April. The reverse trend exhibited by one-year-olds (see next section) indicates that, at this time, the fish are entering their second year of life. These findings lend an element of confidence to the age-determination techniques of Baird (1970).

Although recruitment in May and June takes place along the entire West Coast (Fig. 4), there is a tendency for these juveniles to appear in their largest numbers on the northern fishing grounds first. Then, as the year progresses, a distinct movement towards the south is apparent, 30—40 per cent of the nought-year-old fish being located east of Cape Point in August and September. The relatively high levels of abundance of these fish in the Namaqua and St Helena Bay regions in summer, however, indicates that significant quantities remain in the north. Alternatively it is possible that some return to these grounds during spring.

Table III: Months in which catch rates of nought-year-old pilchard greater than 25 metric tons per standard-boat-day have been recorded

Month	Season
January	1967, 1968, 1969, 1970, 1971
February	1967, 1968, 1971
March	1967, 1969, 1971
April	—
May	1967, 1969, 1970, 1971, 1973, 1975, 1976
June	1965, 1967, 1968, 1971, 1973, 1975
July	1967, 1971, 1975
August	1965, 1968
September	1965, 1968

It is evident from the charts in the Appendix that this pattern of nought-year-old recruitment is fairly regular. Catch rates in excess of 25 metric tons per standard-boat-day were frequently recorded in the latter part of the season, were fairly common in January, less so in February and March and were never attained in April (Table III). Analysis of the size of fish landed clearly indicates that the main nursery grounds are on the West Coast. The modal caudal length of pilchard caught on the Namaqua and St Helena Bay grounds was less than 9,0 cm for 47 of the possible ground-month combinations, as compared with 43 instances for the Saldanha Bay and Hout Bay regions and only 10 for those of Gans Bay and Agulhas.

The movement of nought-year-old pilchard towards the south is apparent in a number of years from the evidence of increased fishing south of Cape Columbine during winter or spring (August/September 1965; July — September 1966; June and August 1967; July and September 1968; July/August 1969; July 1971; July 1972; July/August 1975).

In 1974 there were no catches of this age class (Crawford *et al.* 1978), an anomaly which will be dealt with in greater detail later.

One-year-old fish

Availability of one-year-olds is at a peak in April, catch rates being relatively low in summer

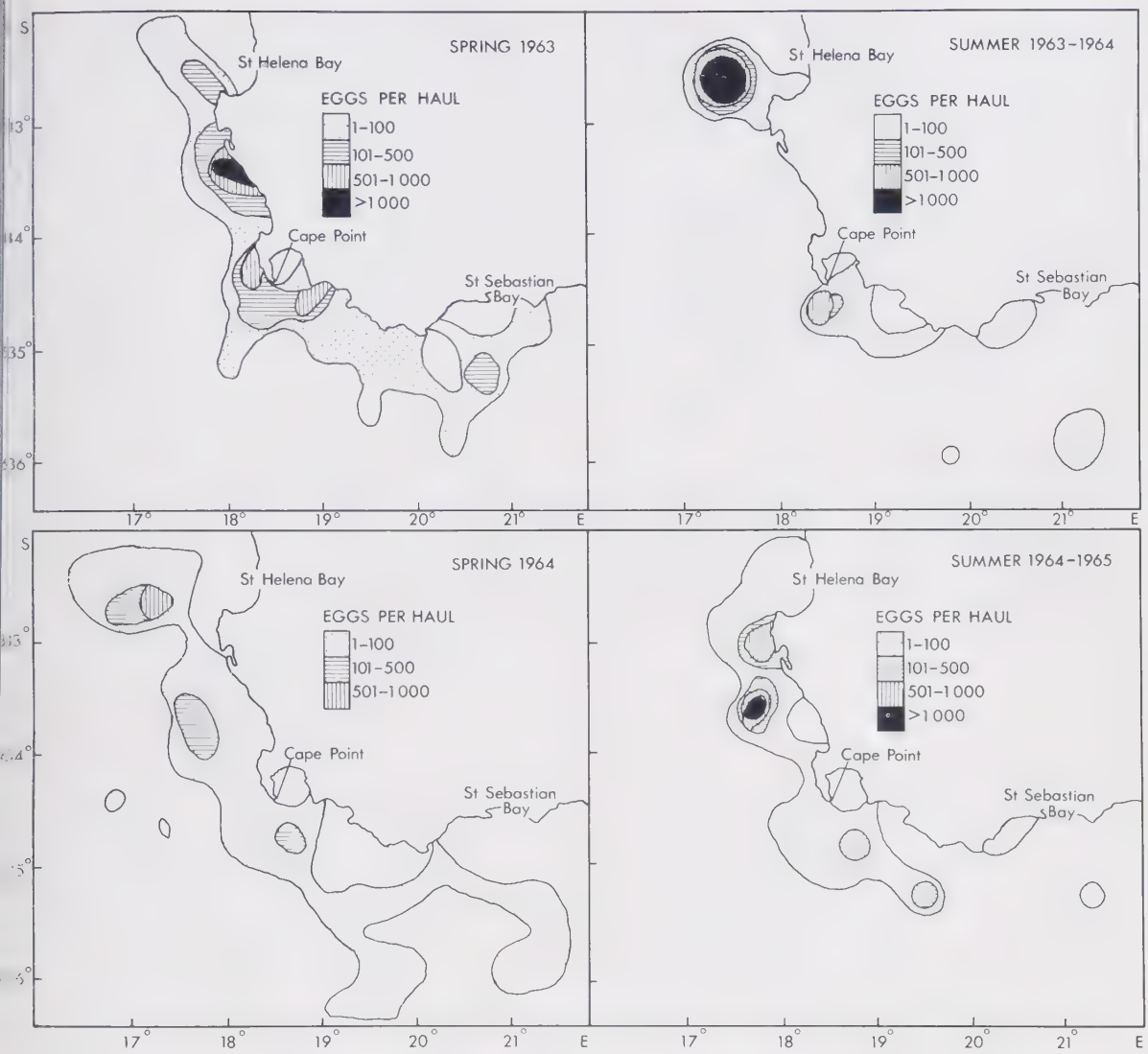

Fig. 6a: Surface distribution of pilchard eggs off South Africa, 1963-1965 (modified from A. S. Anders, Sea Fisheries Institute, unpublished manuscript)

and winter (Fig. 5). As with the youngest age class, one-year-old pilchard are most common on the West Coast and are encountered only infrequently in the Agulhas region (Fig. 4). In addition, abundance indices suggest that they, too, move south during autumn and winter. They are absent from the Namaqua ground after June and from St Helena Bay after August. Because most one- and two-year old pilchard are, in January, found east of Cape Point it appears that this southward movement continues through spring.

Autumn catches of one-year-olds were made in all years except 1964 (when fishing for pilchard with the 12,7-mm mesh net was prohibited) and 1976, and were especially good from 1967 to 1972 and in 1975 (Appendix).

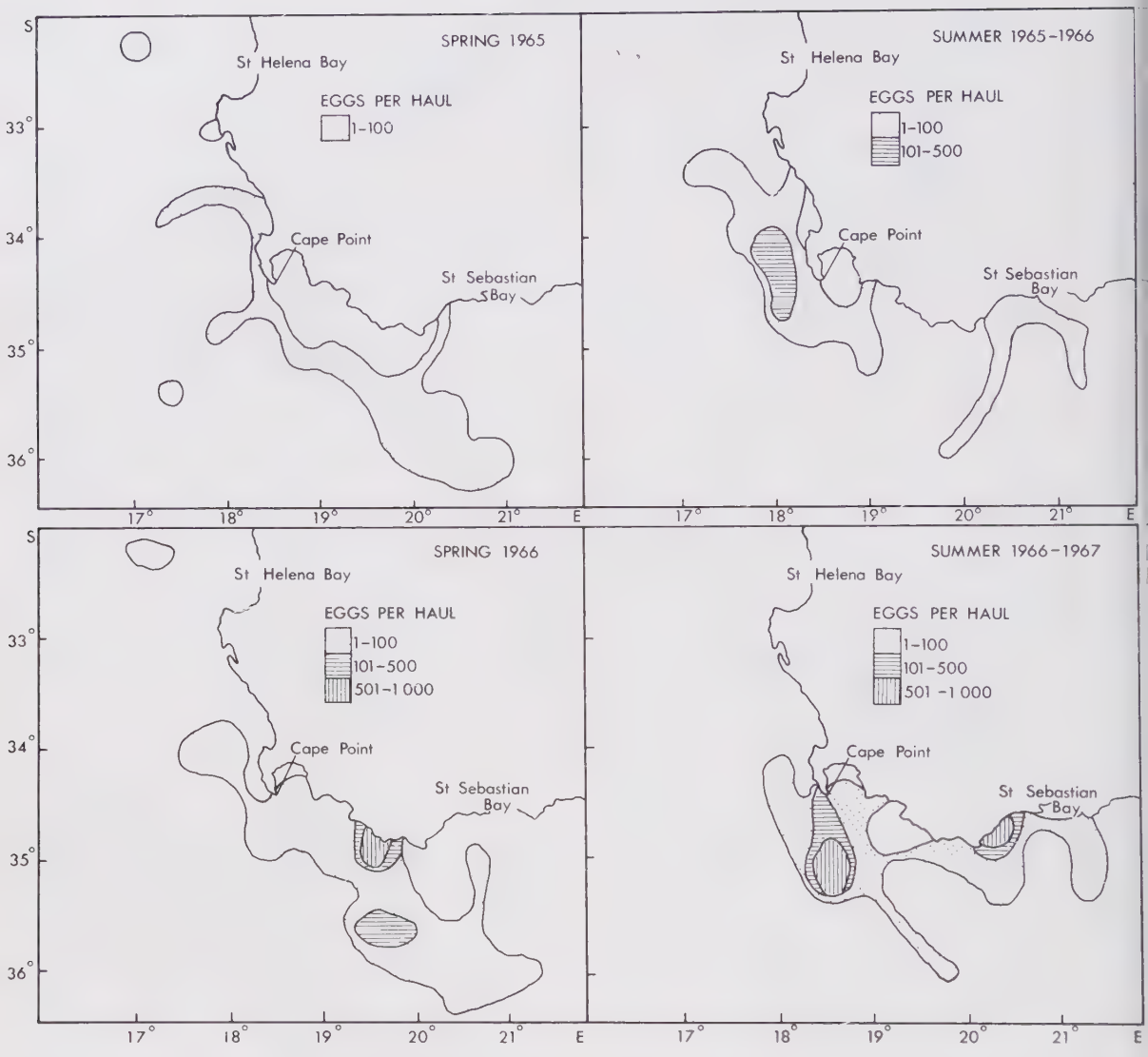

Fig. 6b: Surface distribution of pilchard eggs off South Africa, 1965-1967 (modified from A. S. Anders, Sea Fisheries Institute, unpublished manuscript)

Two- to four-year-old fish

Trends in the availability and distribution of these age groups of pilchard are very similar and they are therefore considered together. All occur characteristically on the southern fishing grounds and in doing so differ markedly from both younger and older pilchard. They are most available at the beginning of the season (Fig. 5), and from late summer or early autumn move in a south-easterly direction past Cape Agulhas, seldom being caught in large numbers after April or May (Fig. 4).

This migration was especially noticeable, for example, in 1964 (Appendix). Two- to four-year-old fish were caught between Saldanha Bay and Cape Agulhas in January, but by February were

encountered only in the waters east of Cape Point and by March were situated off Gans Bay. Except for an isolated pocket north-west of Cape Columbine, they were absent from the fishing grounds in April. In 1965 they remained on the West Coast somewhat later than normal, ranging as far north as the Olifants River in May. By June, however, they were located east of Cape Point, providing particularly rewarding catches in the vicinity of Cape Infanta, and in July were only caught in limited quantities outside Walker Bay. Similar clear trends are apparent for 1966 (January — April), 1967 (January — March), 1968 (January — April), 1969 (February — April), 1970 (February — April), 1971 (February — May), 1972 (February — May), 1973 (January — April), 1974 (January — May), 1975 (January — April) and 1976 (February — June). The movement, therefore, has proved to be highly regular during the past thirteen years.

Two-year-olds are noticeably absent from the commercial pilchard catch in most years (Fig. 3) and often leave the southern fishing area earlier than the three- and four-year-old groups. Evidence to suggest that this cohort tends to be located east of the main fishing grounds comes from the regular winter occurrence of shoals of similar-sized pilchard off the Transkei and Natal coasts. These fish are frequently stranded on the beaches, giving rise to the well known Natal "sardine run" (Davies 1956b, Baird 1971, Heydorn *et al.* 1978). Although pilchards are infrequently observed between Cape Agulhas and the Transkei during autumn and limited experimental fishing in the region has failed to reveal large concentrations of fish, Hecht (1976) records that pilchard are preyed on extensively by hake trawled south of Port Elizabeth from April to June. In fact, in May and June they made up the entire stomach contents of more than 85 per cent of the hake sampled. Conversely, pilchard have not been found to contribute to the diet of hake caught in the Benguela Current region (Chiapowski 1977). In addition, Bulgarian trawlers using midwater gear recorded catches of pilchard off Mossel Bay (at 34° 58′S, 22° 53′ E) and off Port Elizabeth (at 34° 21′ S, 25° 51′ E) in September 1977. Unfortunately there is no information on the size of these fish. However, it would seem that pilchard, after passing Cape Agulhas, move to a midwater position and thus become available to hake in the Port Elizabeth vicinity.

Five- and six-year-old fish

Five- and six-year-old pilchard have not been caught in large numbers since 1966 (Crawford *et al.* 1978), the year in which fishing for all species with the small-meshed (12,7-mm) net was first permitted (Crawford 1981). Use of this net was initially restricted to the anchovy resource, but the frequent occurrence of anchovy with other species in mixed shoals rendered enforcement of such legislation impractical.

The older pilchard age groups are most available from February to May or June (Fig. 5). Although they have contributed in some measure to the summer-autumn catch east of Cape Point, abundance indices (Fig. 4) show that they occur more commonly in the northern fishing areas where catch rates, especially on the Namaqua ground, are highest during autumn and winter.

These observations are, to a large extent, based on three years' data (1964 — 1966) only, but confirmation comes from the findings of Davies (1956b) and from pilchard catch rates calculated for the period 1950 — 1955 (Fig. 5), when 92 per cent of all catches were located between Lambert's Bay and St Helena Bay (Davies *op. cit.*) and younger pilchard only made up a small portion of the landings (Crawford *et al.* 1978).

DISCUSSION

The behaviour of the pilchard population off South Africa is closely related to the environmental conditions in the region (Crawford *et al.* 1980). Spawning is almost entirely confined to spring and summer, the main upwelling seasons, therefore ensuring an abundant food supply for developing larvae and juveniles (Crawford *et al. op. cit.*). In recent years the largest concentrations of eggs have been found east of Cape Point where, because of the influence of the Agulhas Current, the water in the upper layers is well mixed and warm. Previously, heavy spawning was also recorded on the St Helena Bay and Saldanha Bay grounds. In these areas the eggs were generally located off shore (Fig. 6) in warm water of oceanic origin (Crawford 1980). As the initial rate of development increases exponentially with temperature (King 1977a), spawning in warmer water is likely to enhance survival of the early ichthyoplankton stages by reducing the age at which complete retinal pigmentation is attained and so decreasing mortality caused by predation (Lasker 1964). Also, abnormal development takes place under experimental conditions at temperatures less than 13° C (King *op.cit.*).

It is on the Namaqua and St Helena Bay grounds that the initial recruitment of young fish, in May or June, is heaviest, even though spawning in the northern region has in recent years been virtually terminated. Therefore much of the ichthyoplankton originating from the southern areas must subsequently be carried in a westerly and then a northerly direction. The eggs and larvae are planktonic, and surface currents set in motion by the prevailing south-easterly winds of spring and summer could possibly transport large quantities westwards around Cape Point (Duncan and Nell 1969). In addition, Bang and Andrews (1974) have demonstrated the presence of a strong shelf-edge frontal jet, which shoots large volumes of water at rapid speed (100 cm • s^{-1} at the core) in a northerly direction along the West Coast. Shelton and Hutchings (1979) are of the opinion that this jet may be important in the dispersal of anchovy ichthyoplankton, and probably also pilchard.

In winter the highest plankton concentrations are found in a narrow strip inshore, with maximum standing stocks in the north (Crawford *et al.* 1980). It is here that catch rates of nought-year-old pilchard, which feed predominantly on zooplankton (King and Macleod 1976), are initially best. The sharp increase in the availability of this age group may result from both growth to a size at which they are fully selected by the fishing gear and an initiation of shoaling behaviour.

As upwelling recommences during spring, many of these fish move southwards into newly productive areas (Crawford *et al.* 1980). Inshore counter-currents (Duncan and Nell 1969) may assist in the migration. However, significant numbers also remain on the northern grounds until late winter or spring of the following season, when they join with the latest recruits in their movements towards and around Cape Point.

Pilchard generally do not become reproductively active until well into their second year of life. In spring and summer, two- to four-year-olds occupy the southern fishing areas. Here, as mentioned earlier, relatively warm water promotes rapid development of the early ichthyoplankton stages. Then, from April or May, these age groups move in an easterly direction past Cape Agulhas, where they seem to occur in midwater. At an age of approximately one year the pilchard develops a fine filtering mechanism (King and Macleod 1976), which enables it to feed on phytoplankton in addition to zooplankton. The chlorophyll-maximum layer is frequently sub-surface east of Cape Agulhas (Crawford *et al.* 1980), and presumably the location of these fish in the water column is related to food abundance.

The best yields of five- and six-year-olds have been recorded off the West Coast, where catch rates have been highest in autumn and winter. Although they are in the same area as juvenile pilchard at this time, the two groups are not necessarily in direct competition for food, because the older fish are able to make maximum use of the phytoplankton resources. Davies (1956b) attributed their low availability in spring and summer to the fact that they consistently moved off shore to spawn. A severe decline in annual egg production in the St Helena Bay vicinity has coincided with a greatly reduced contribution by these age groups to the commercial landings.

It is generally recognized that the pilchard stocks off South Africa and South West Africa are independent entities. There is little evidence of large-scale movement between the two regions (Stander and Le Roux 1968, Newman 1970b) and catch-per-unit-effort trends have shown considerable discrepancies.

In South West African waters the pilchard has two main spawning seasons, spring and summer, which are associated with separate geographical areas, off Walvis Bay and Möwe Point respectively. These regions have contrasting hydrographical conditions, leading to speculation that two South West African stocks exist (Schülein 1971, King 1977b, O'Toole 1977). Closer investigation, however, may yet reveal a situation analogous to that which previously obtained in South Africa, that is of two isolated spawning areas arising from the different distribution patterns of the various age components of one population. Some similarities in the behaviour of the pilchard in these two territories are already apparent. Spawning off Walvis Bay, for example, coincides with a peak in upwelling, and the subsequent dispersal of ichthyoplankton is in a northerly direction (O'Toole 1977). Also, Schülein (1973) has demonstrated that the appearance of juvenile pilchard in the catches is associated with southerly currents, and he has postulated that the nursery grounds are situated to the north of the fishing area.

Two other commercial fisheries, those of the Californian sardine *Sardinops caerulea* and the Japanese sardine *S. melanosticta,* also warrant mention here. Off California a decline in the sardine landings was accompanied by a progressive southward shift in the position of most catches, until the majority were located in the relatively warm water off Baja California (Murphy 1966). A parallel situation developed in the South African pilchard fishery when catches of this species fell dramatically

during the mid sixties. Elimination of the older age classes meant that the range of adult fish contracted to the south and particularly to the warmer waters east of Cape Point. Examination of the age composition of the Californian sardine landings, as presented by Murphy *(op.cit.)*, reveals that the decrease in the range of this species coincided with a considerably reduced contribution to the commercial catch of fish aged five and older.

The performance of the sardine fishery in Japan has been characterized by the same enormous fluctuations which have dominated those off South Africa, South West Africa and California. Most of the spawning occurs in the southern areas, which are influenced by the warm Kuroshio Current, and within 20—30 miles of the coast. Dispersal of the ichthyoplankton is in a northerly direction towards the more productive, cooler water of the south-flowing Oyashio Current (Nagasaki 1973). Spawning by *S. ocellata* in warm water east of Cape Point and subsequent transportation of eggs and larvae into the Benguela Current system are similar to this mechanism.

The high degree of regularity in the seasonal distribution and availability of the various age components of the pilchard population off South Africa should greatly facilitate the incorporation of these patterns in a simulation model of the fishery. It also holds considerable practical advantages for assessment and management of the resource (Crawford and Shelton 1978, Crawford *et al.* 1980).

Only one major anomaly has occurred during the period of observation: the complete absence of nought-year-old pilchard from the commercial landings of 1974. Two possible explanations have been postulated for this phenomenon. Heydorn *et al.* (1978) suggested that it may have resulted from an eastward displacement of the parent stock during the 1973/74 spawning season, and they drew attention to the unusual occurrence of nought-year-old pilchard off the Natal coast in 1974. On the other hand, the 1974 fishing season was brought to a premature close by the early completion of catch quotas. Nought-year-old recruits are generally caught after April but, by that time in 1974, much of the fishing had already been suspended (Newman and Crawford 1980).

Whatever the cause, the 1974 year-class was only lightly exploited during its first two seasons in the fishery, with the result that large yields of two-year-old pilchard were harvested in the 1976 season. It is suggested, therefore, that considerable benefits might accrue from directing fishing at particular year-classes only (Crawford *et al.* 1980).

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APPENDIX

PILCHARD CATCH LOCATIONS 1964 — 1976

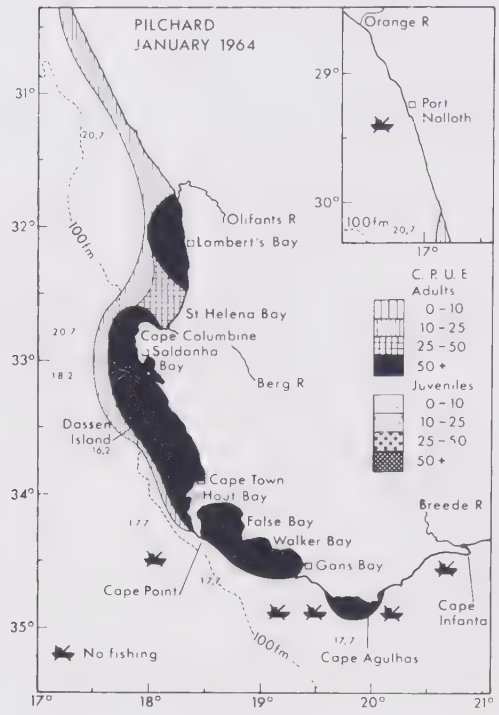
From 1969 to 1976 no charts are shown for September — December inclusive, because exploitation of pilchard was prohibited during these months.

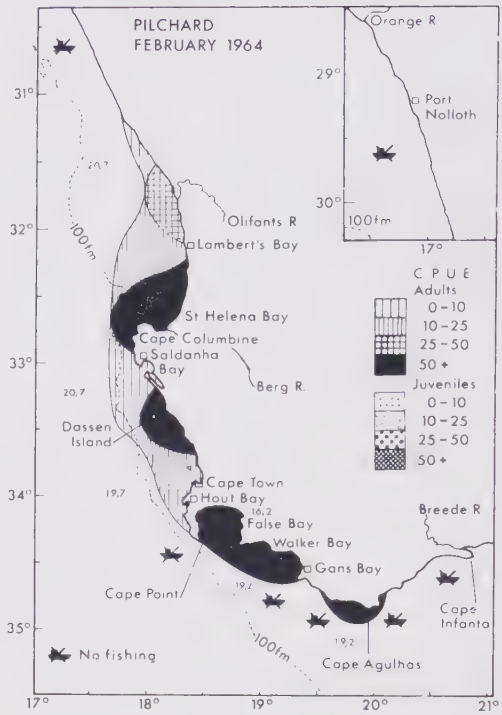
Levels of catch per unit effort (C.P.U.E.) are indicated as metric tons per standard-boat-day.

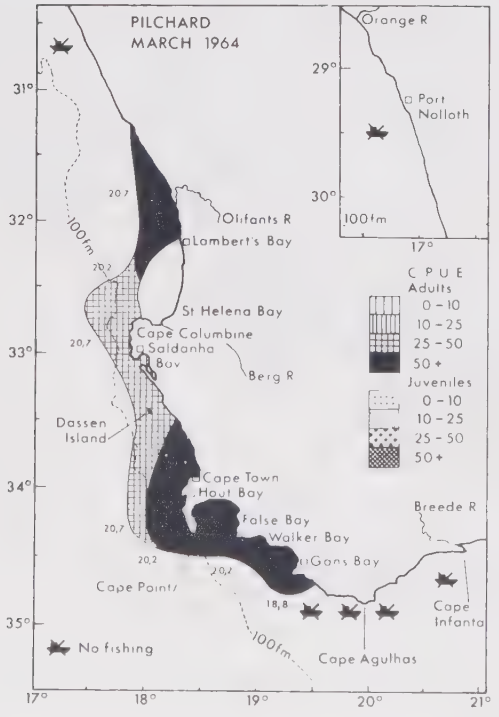
Modal caudal lengths (cm) of fish from different areas are shown adjacent to catch locations. Growth rates may be expected to vary between seasons, but some indication of age is provided by the von Bertalanffy growth equation calculated by Baird (1970) used in conjunction with Newman's (1970a) conversion factor for bringing total length to caudal length:

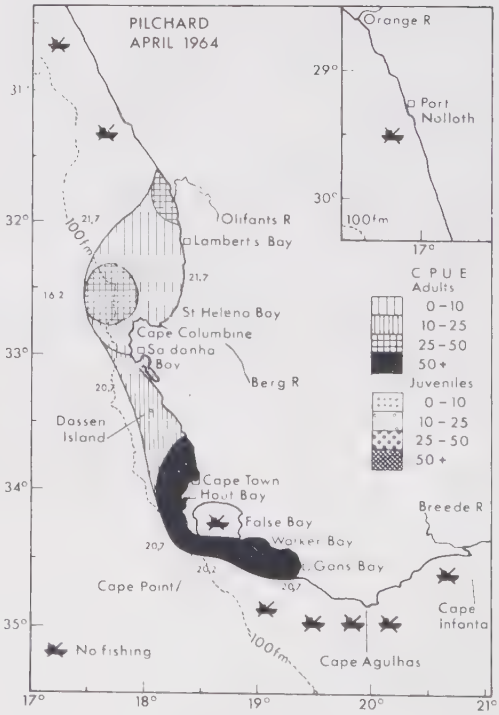
Age (years)	Predicted caudal length (cm)
1	11.1
2	14.1
3	16.4
4	18.2
5	19.7
6	20.9
7	21.9
L_∞	25.7

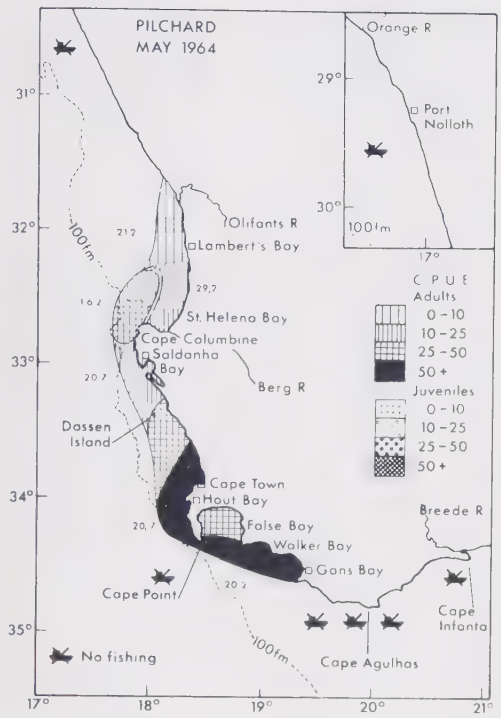
Areas in which there was no deployment of fishing effort are shown.


PILCHARD
JANUARY 1964
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +


PILCHARD
FEBRUARY 1964
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +


PILCHARD
MARCH 1964
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +


PILCHARD
APRIL 1964
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +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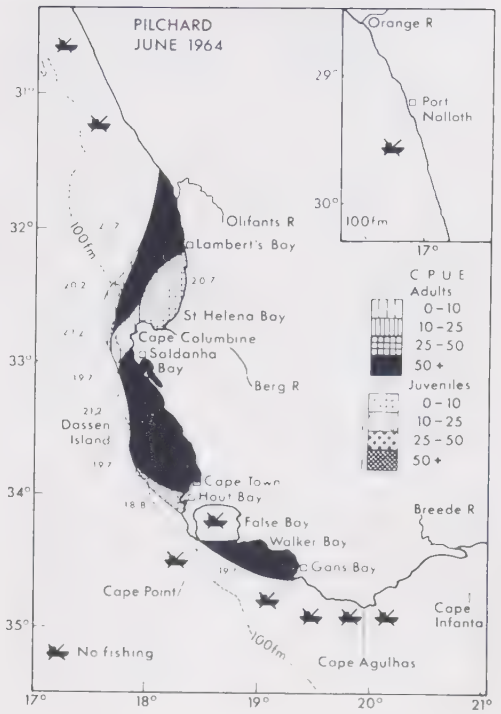
MAY 1964
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +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JUNE 1964
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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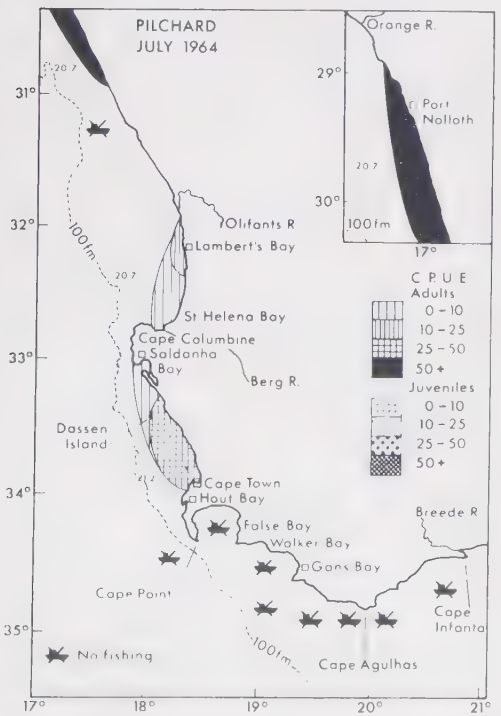
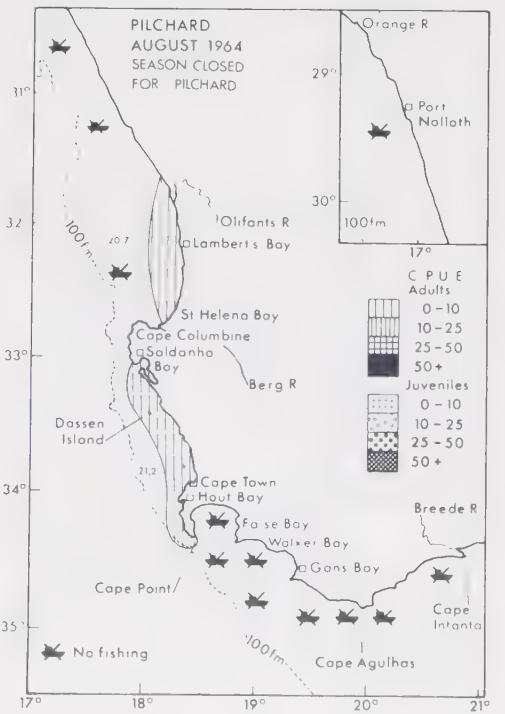
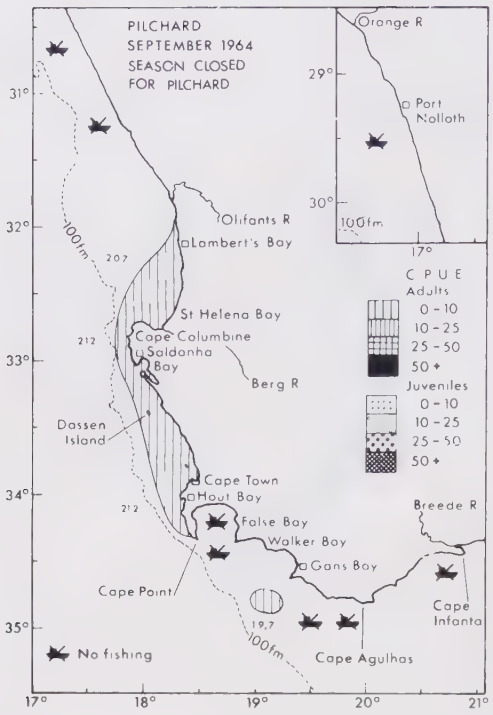
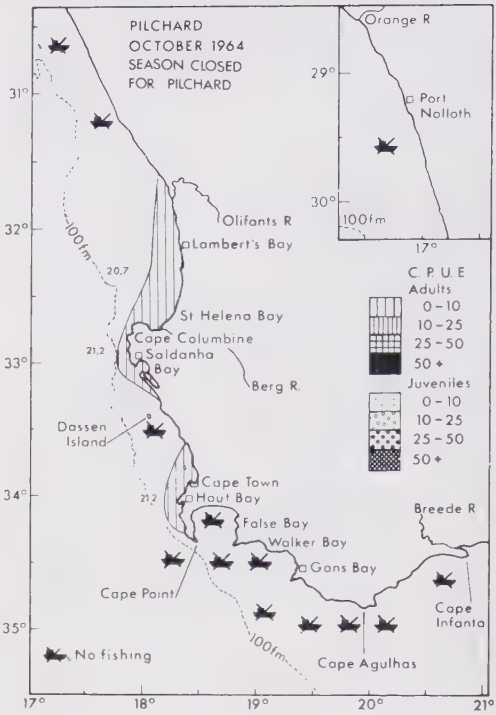
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +


PILCHARD
JULY 1964
Orange R.
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +


PILCHARD
AUGUST 1964
SEASON CLOSED
FOR PILCHARD
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +


PILCHARD
SEPTEMBER 1964
SEASON CLOSED
FOR PILCHARD
Orange R
Port Nolloth
100fm
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
20,7
21,2
19,7
29°
30°
31°
32°
33°
34°
35°
17°
18°
19°
20°
21°


PILCHARD
OCTOBER 1964
SEASON CLOSED
FOR PILCHARD
Orange R
Port Nolloth
100fm
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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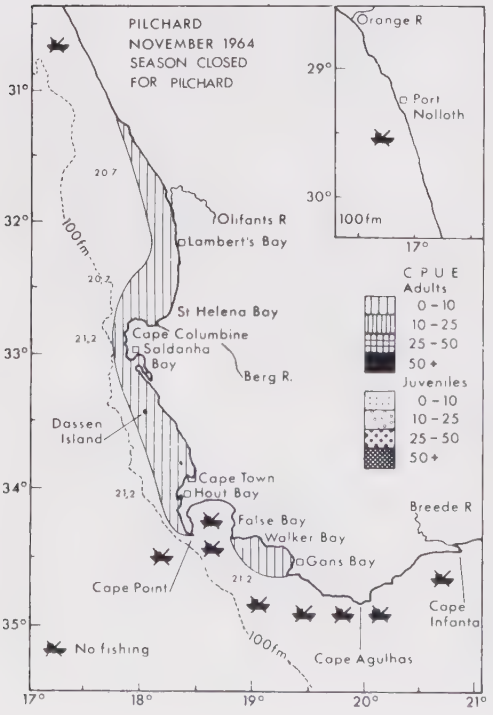
PILCHARD
NOVEMBER 1964
SEASON CLOSED
FOR PILCHARD
Orange R
Port Nolloth
100fm
C P U E
Adults
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25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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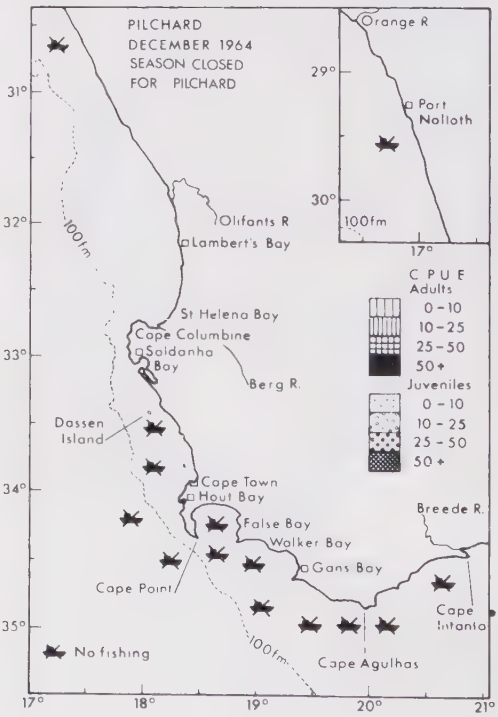
PILCHARD
DECEMBER 1964
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FOR PILCHARD
Orange R
Port Nolloth
100fm
C P U E
Adults
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50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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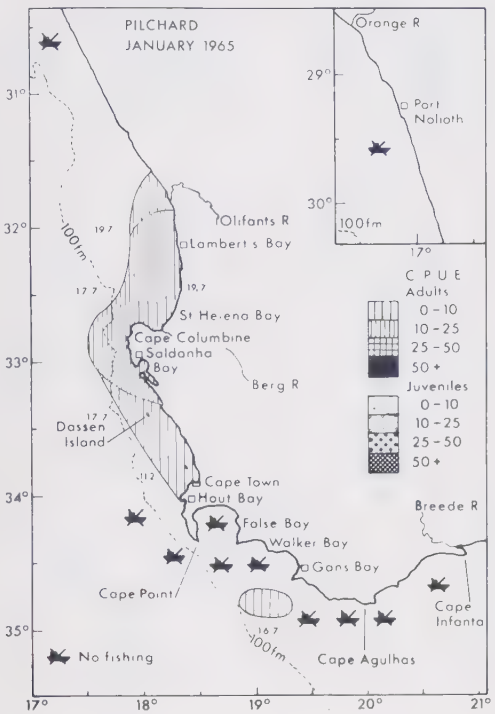
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JANUARY 1965
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Lambert's Bay
St Helena Bay
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Berg R
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Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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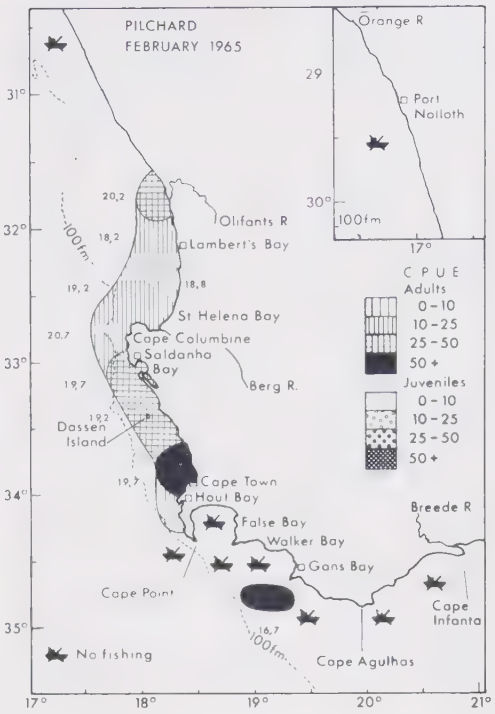
PILCHARD
FEBRUARY 1965
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Port Nolloth
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Lambert's Bay
St Helena Bay
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Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
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Juveniles
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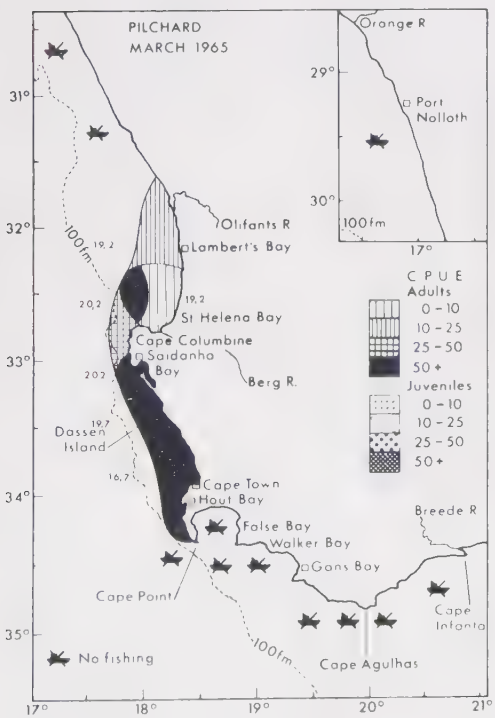
50 +


PILCHARD
MARCH 1965
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Berg R.
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Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
Adults
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Juveniles
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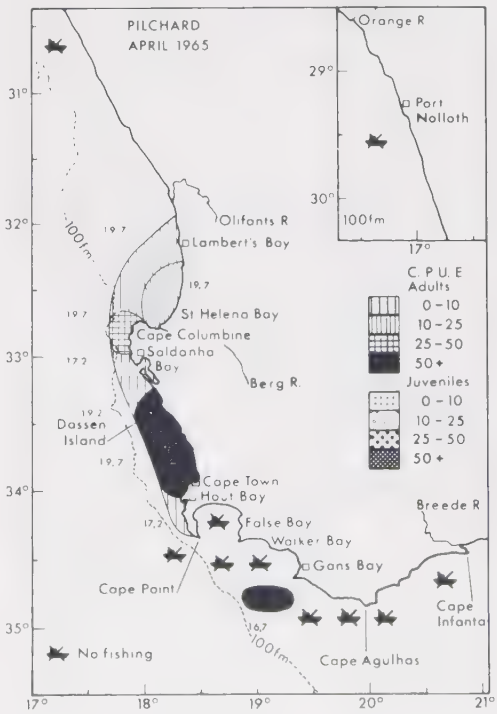
PILCHARD
APRIL 1965
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
Adults
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10 - 25
25 - 50
50 +
Juveniles
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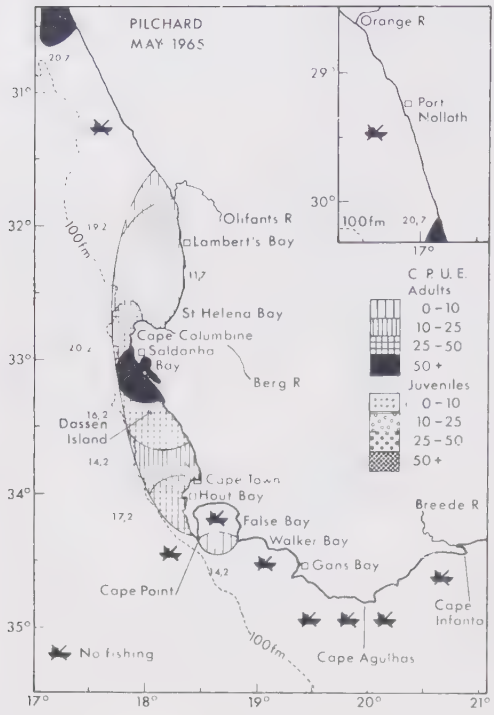
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MAY 1965
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Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
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10 – 25
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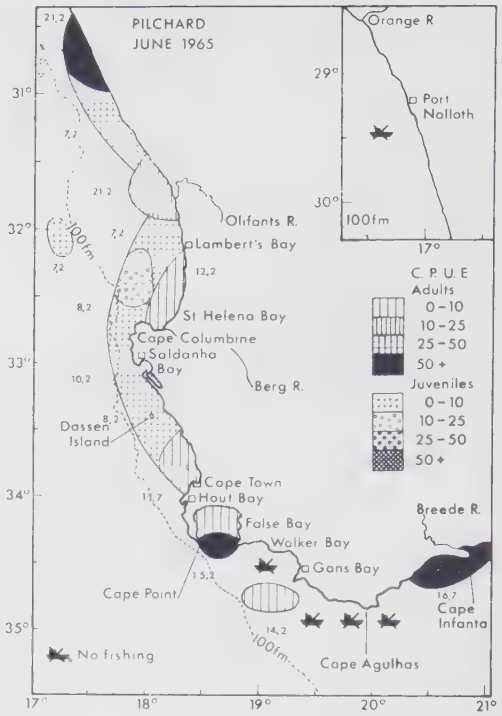
PILCHARD
JUNE 1965
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Port Nolloth
100fm
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C. P. U. E
Adults
0 – 10
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25 – 50
50 +
Juveniles
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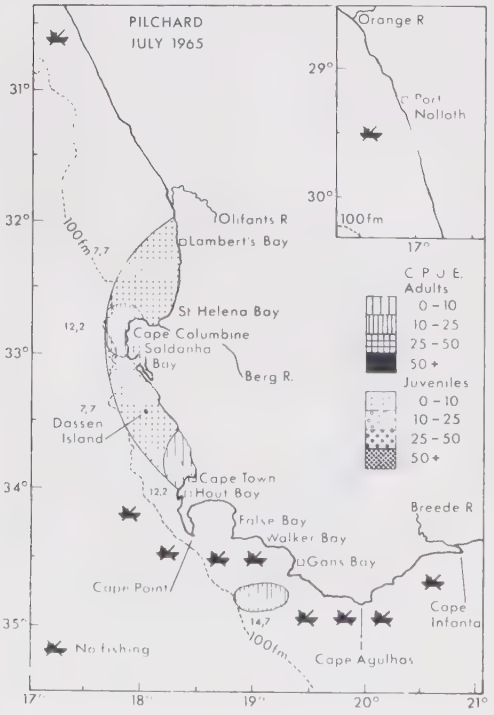
PILCHARD
JULY 1965
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Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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50 +
Juveniles
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10 – 25
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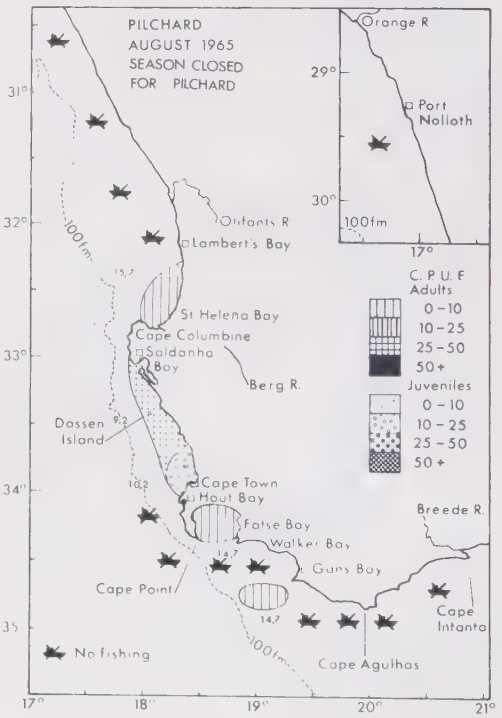
PILCHARD
AUGUST 1965
SEASON CLOSED
FOR PILCHARD
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
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Cape Point
Cape Infanta
Cape Agulhas
No fishing
C. P. U. E
Adults
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Juveniles
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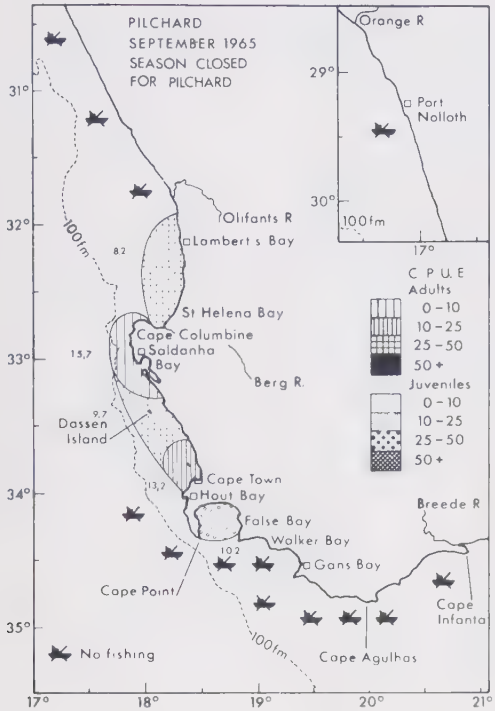
PILCHARD
SEPTEMBER 1965
SEASON CLOSED
FOR PILCHARD
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
Adults
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Juveniles
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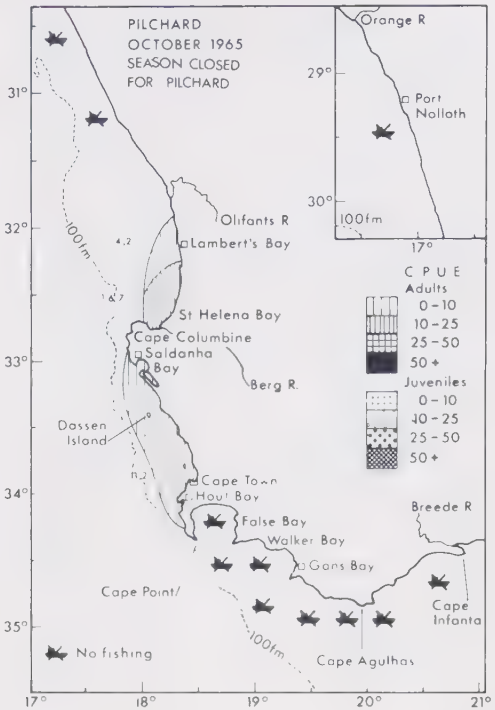
PILCHARD
OCTOBER 1965
SEASON CLOSED
FOR PILCHARD
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point/
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
Adults
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Juveniles
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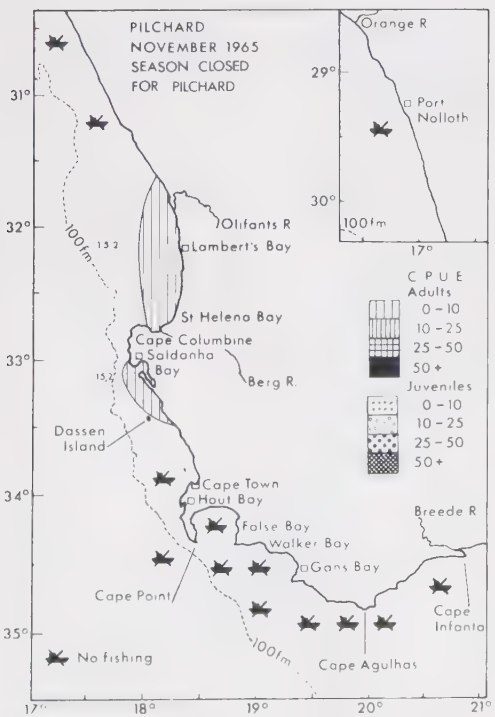
PILCHARD
NOVEMBER 1965
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FOR PILCHARD
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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C P U E
Adults
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Juveniles
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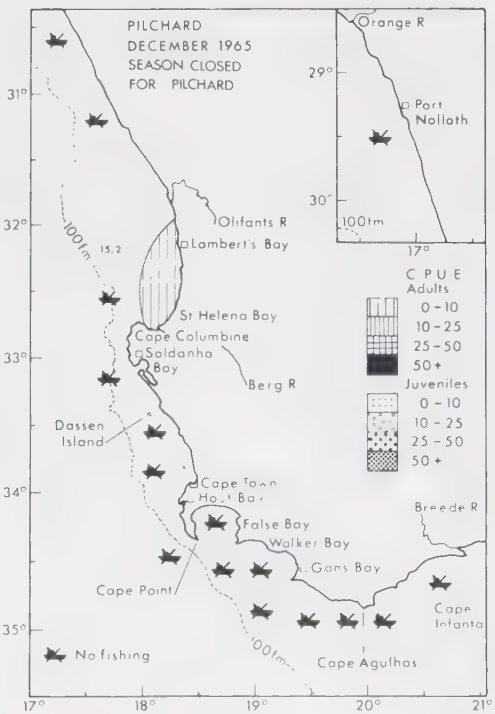
PILCHARD
DECEMBER 1965
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FOR PILCHARD
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
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Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
C P U E
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Juveniles
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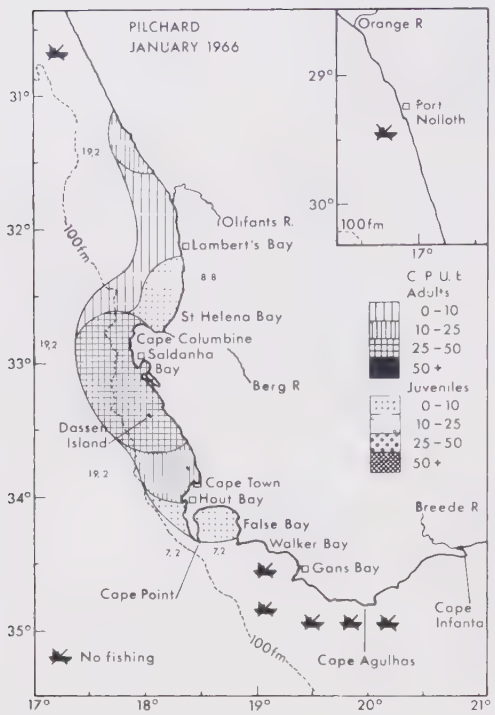
PILCHARD
JANUARY 1966
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Port Nolloth
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Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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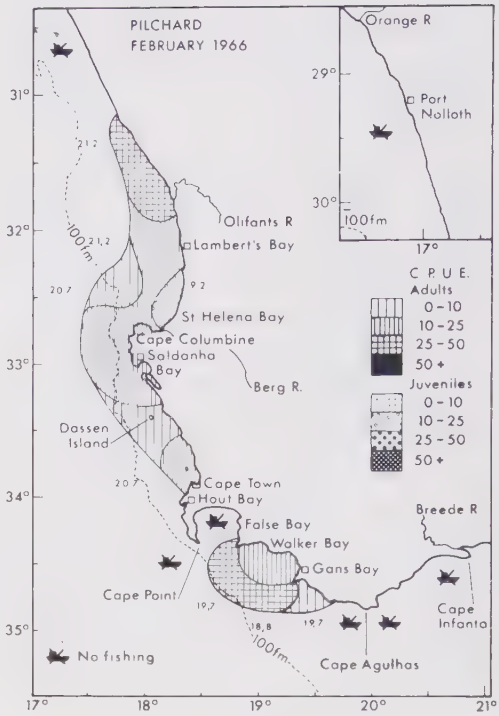
PILCHARD
FEBRUARY 1966
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100fm
Olifants R
Lambert's Bay
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Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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Juveniles
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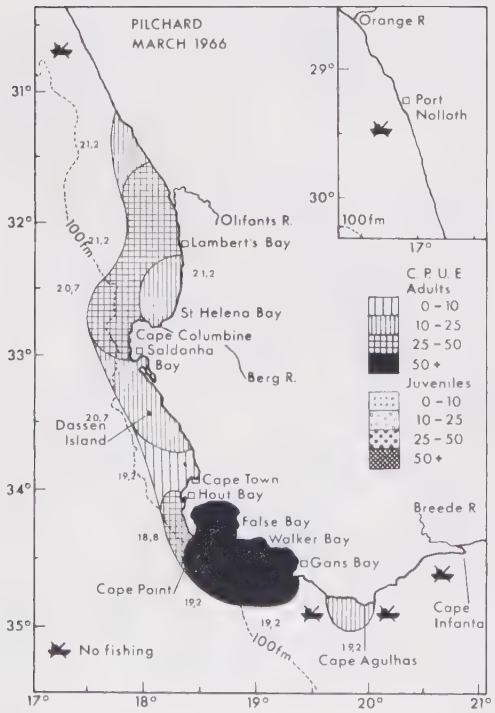
PILCHARD
MARCH 1966
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Port Nolloth
100fm
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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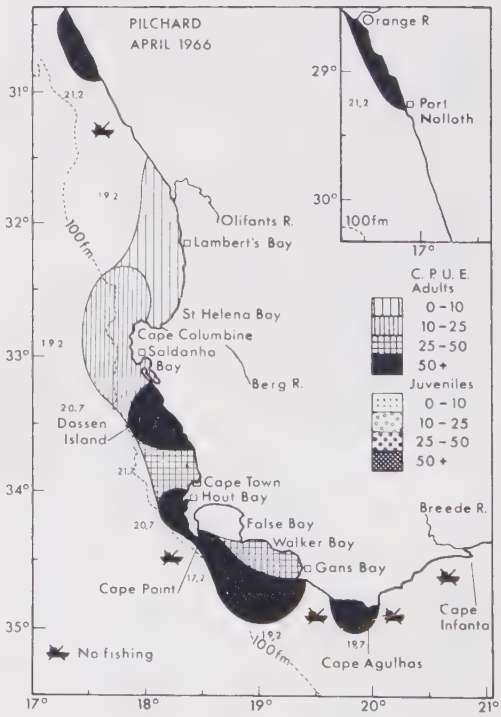
PILCHARD
APRIL 1966
Orange R
Port Nolloth
100fm
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C. P. U. E.
Adults
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50 +
Juveniles
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10 – 25
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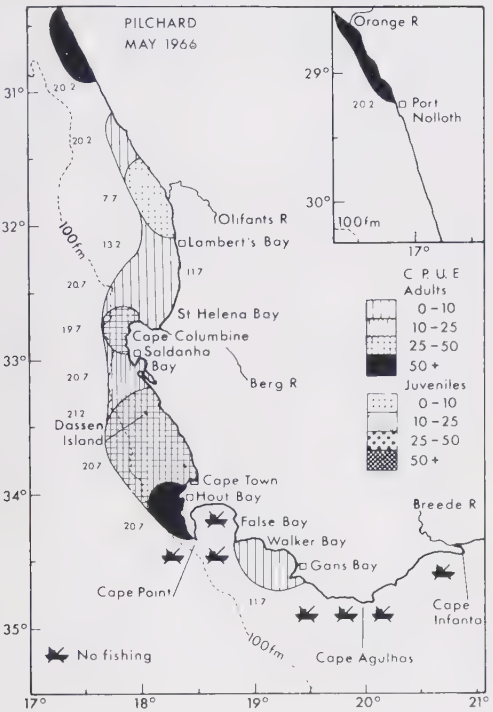
PILCHARD
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100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
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Cape Agulhas
Cape Infanta
No fishing
C P U E
Adults
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Juveniles
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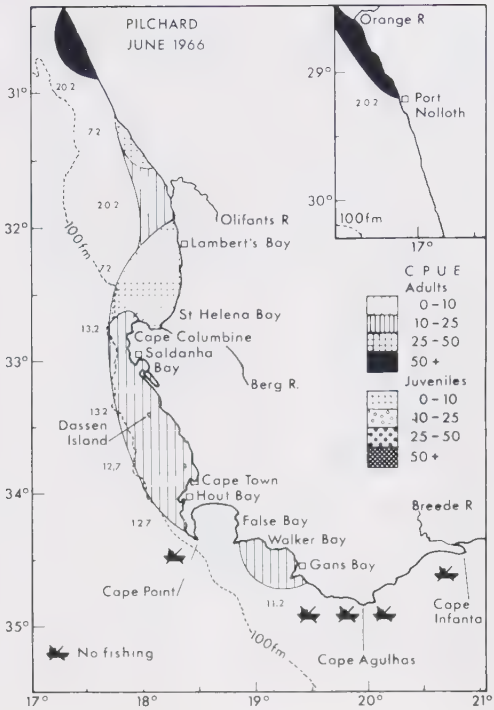
PILCHARD
JUNE 1966
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Cape Columbine
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Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
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Gans Bay
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Cape Agulhas
Cape Infanta
No fishing
C P U E
Adults
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Juveniles
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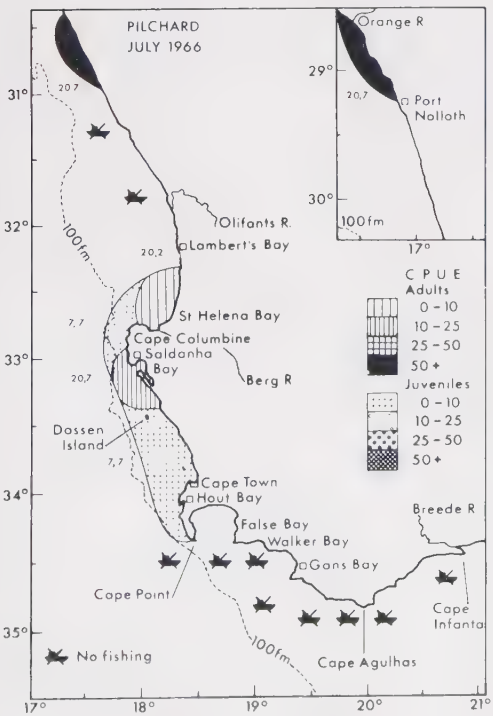
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JULY 1966
Orange R
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St Helena Bay
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Saldanha Bay
Berg R
Dassen Island
Cape Town
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No fishing
C P U E
Adults
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50 +
Juveniles
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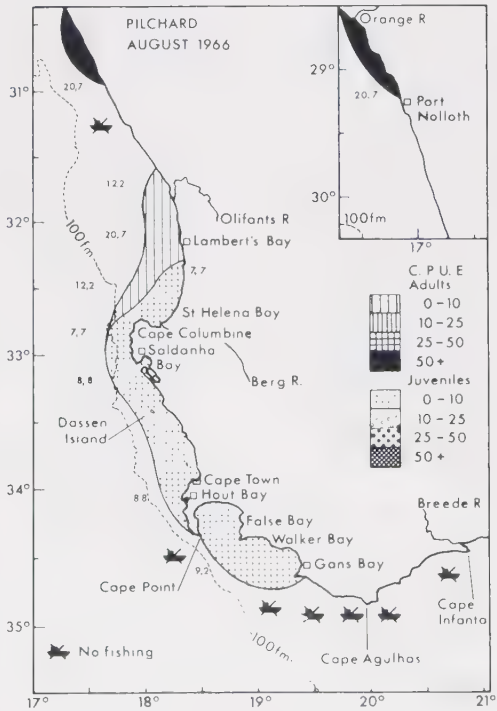
PILCHARD
AUGUST 1966
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100fm
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Agulhas
Cape Infanta
No fishing
C. P. U. E
Adults
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Juveniles
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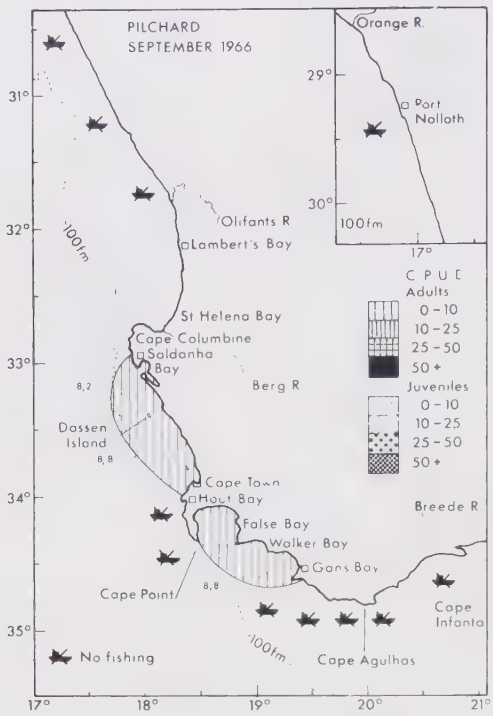
PILCHARD
SEPTEMBER 1966
Orange R.
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
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35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
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8,8
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
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25 – 50
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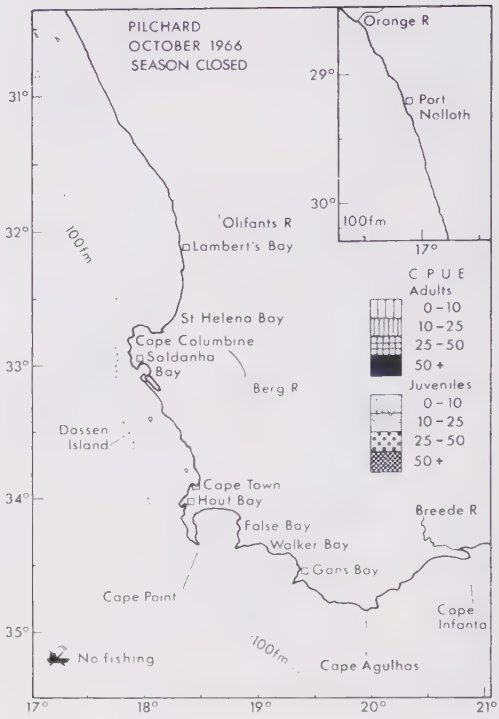
PILCHARD
OCTOBER 1966
SEASON CLOSED
Orange R
Port Nolloth
29°
30°
100fm
17°
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35°
Olifants R
Lambert's Bay
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No fishing
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10 – 25
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Juveniles
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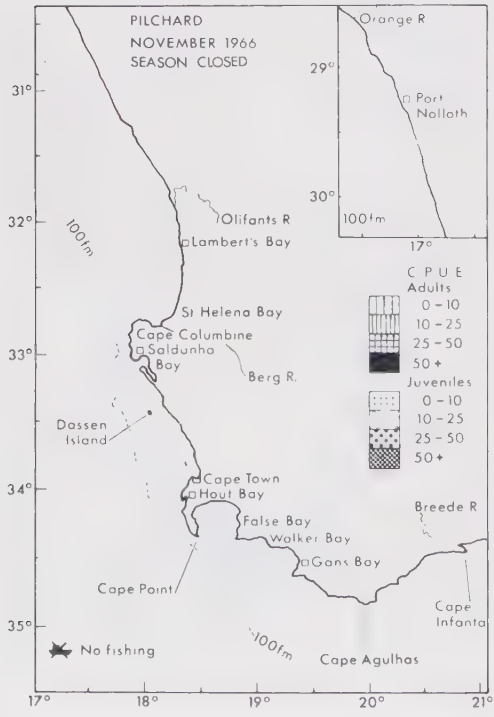
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Port Nolloth
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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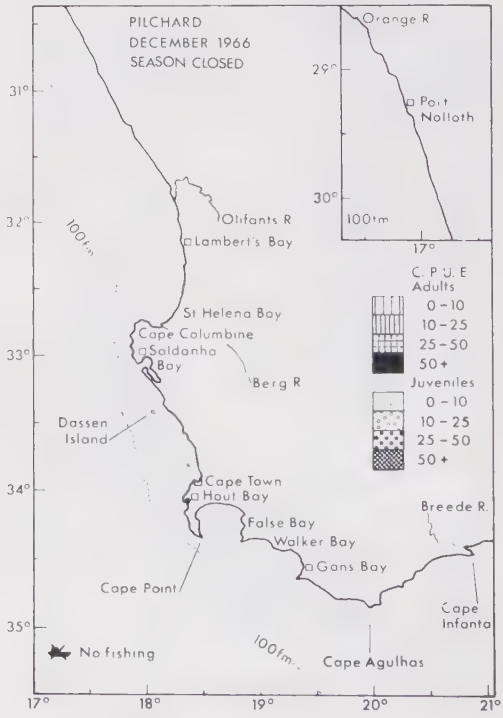
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Lambert's Bay
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Saldanha Bay
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Gans Bay
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Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
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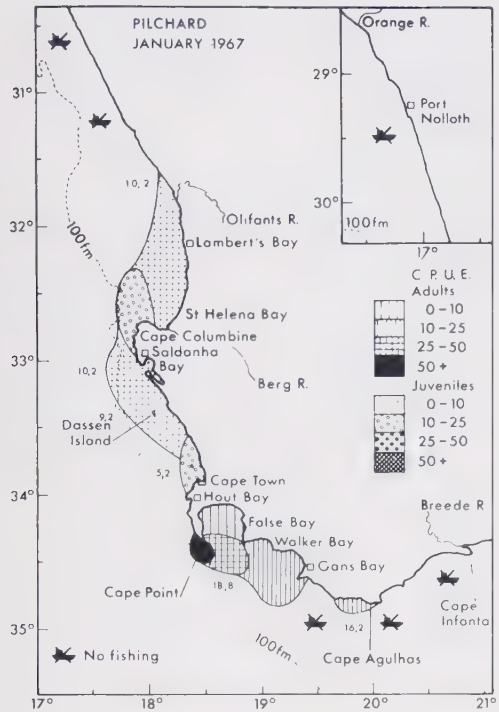
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Berg R.
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Cape Agulhas
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Juveniles
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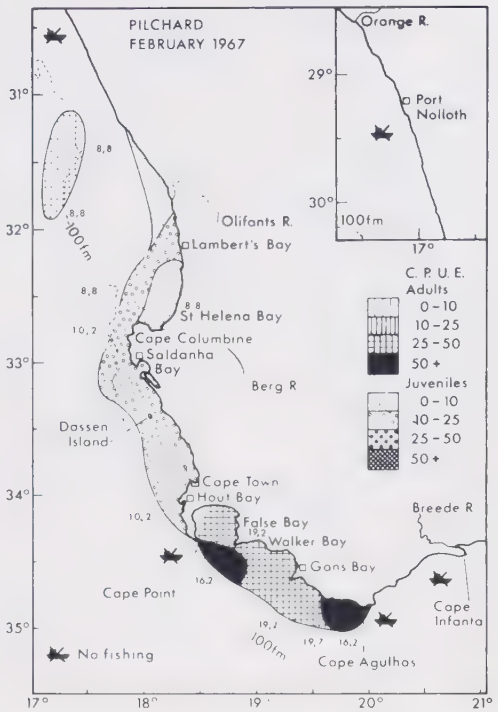
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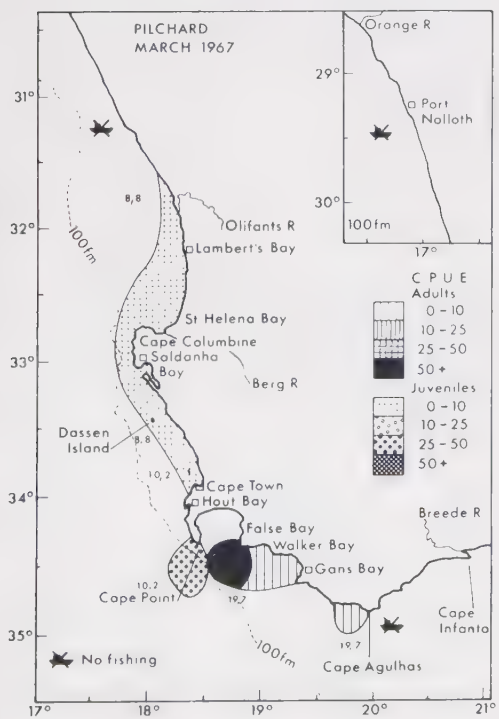
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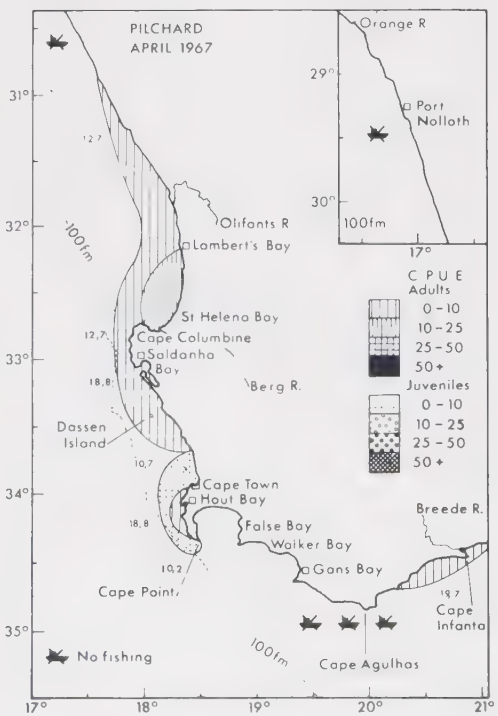
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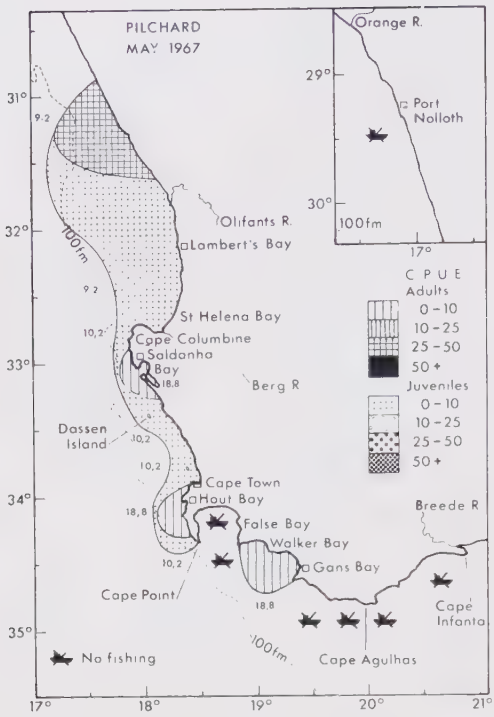
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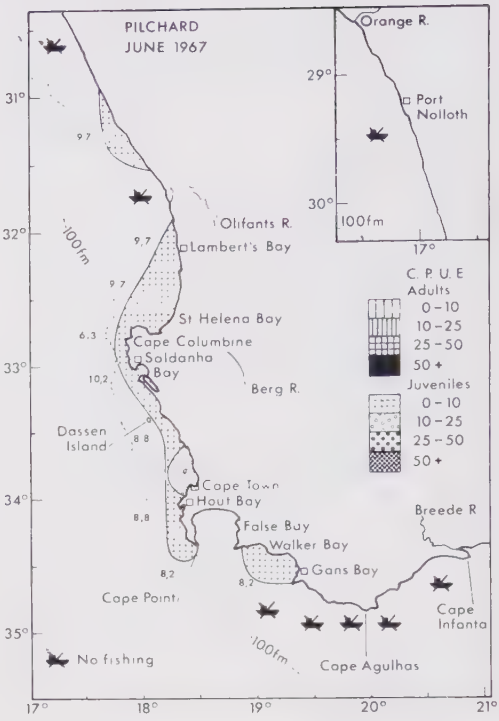
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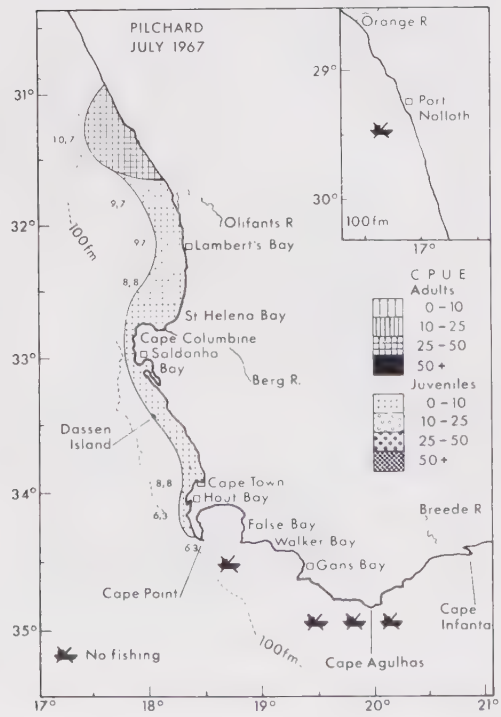
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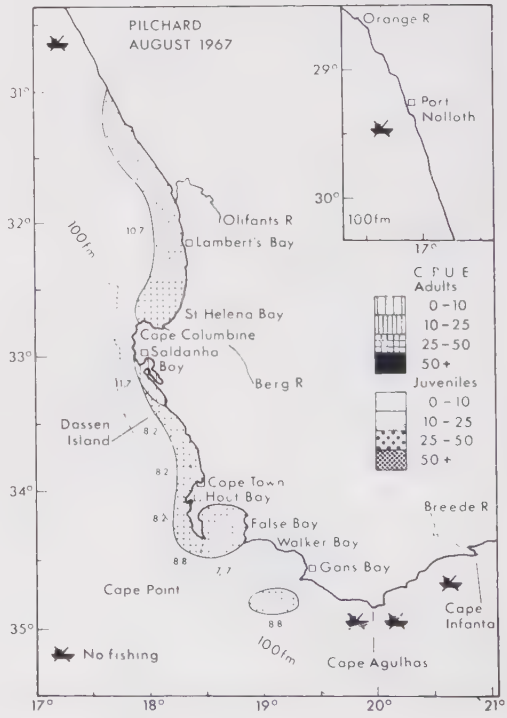
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AUGUST 1967
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Lambert's Bay
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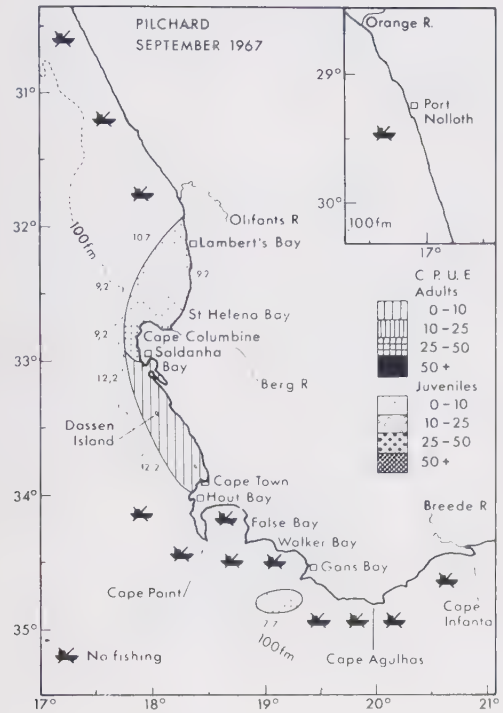
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C. P. U. E
Adults
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Olifants R
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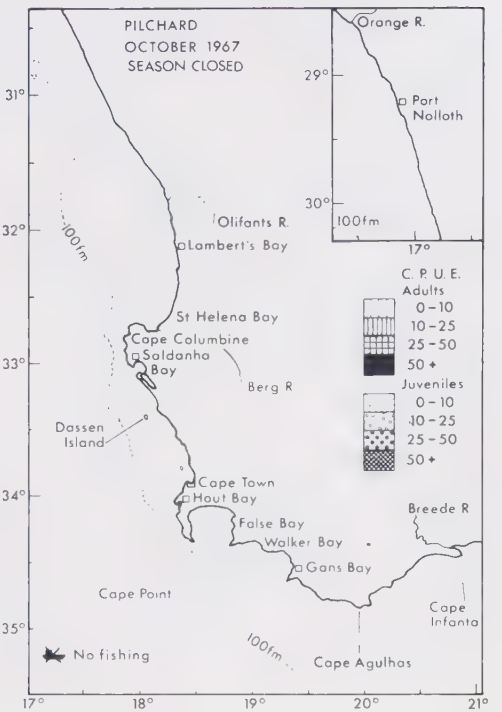
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OCTOBER 1967
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Port Nolloth
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Adults
0 – 10
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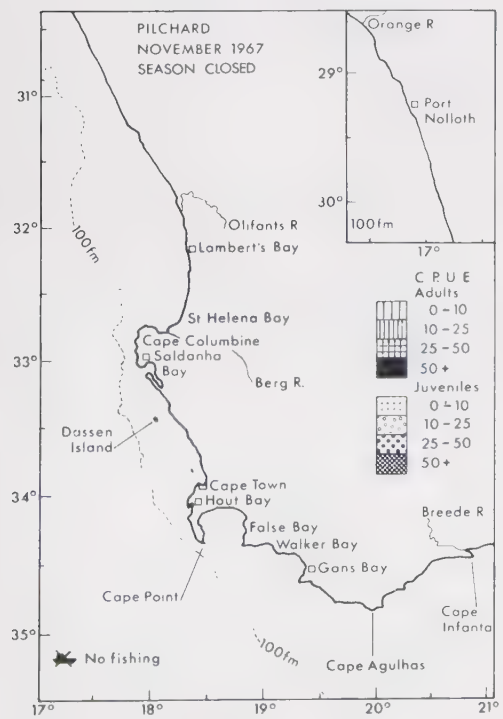
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C P U E
Adults
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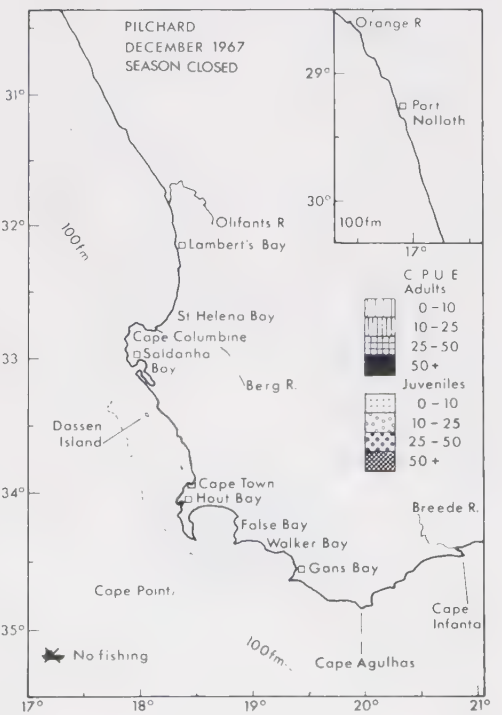
No fishing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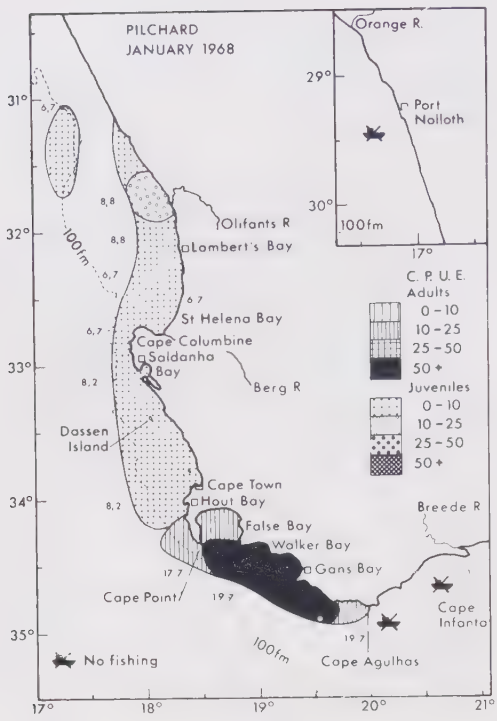
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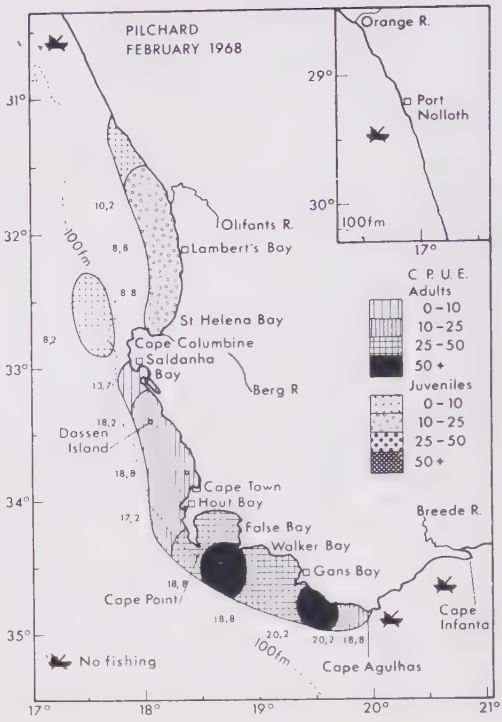
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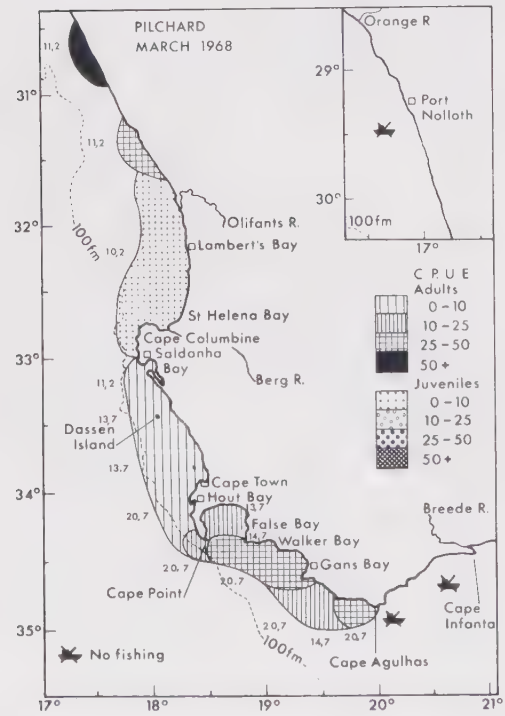
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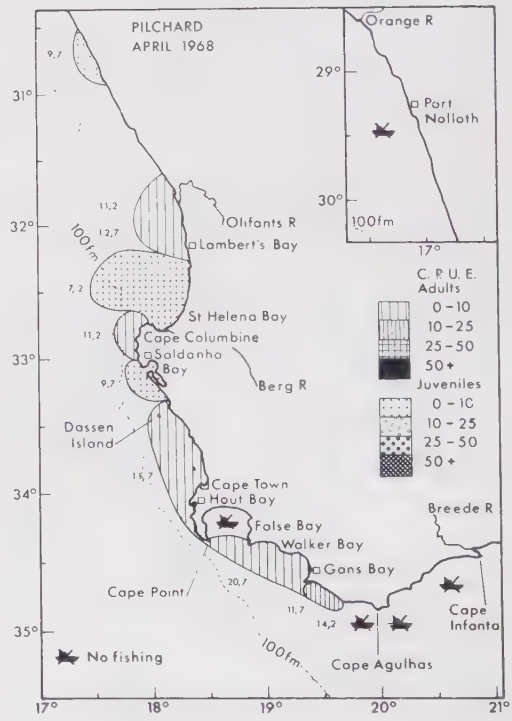
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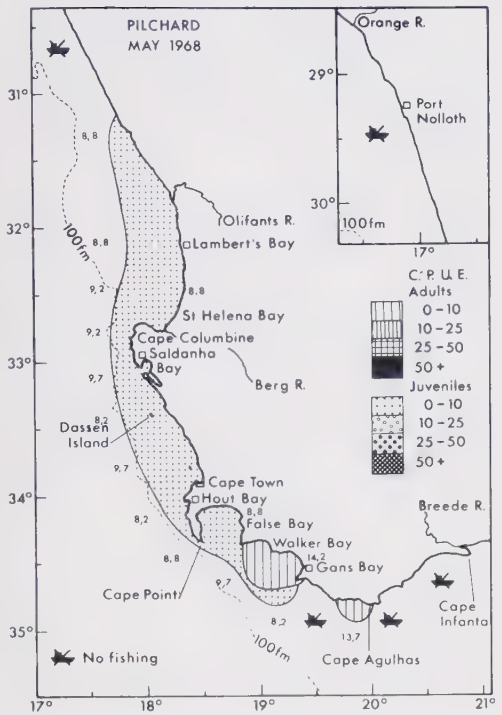
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MAY 1968
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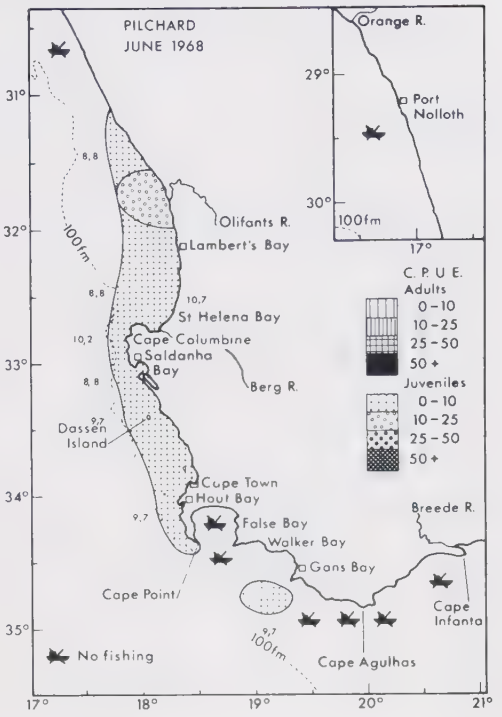
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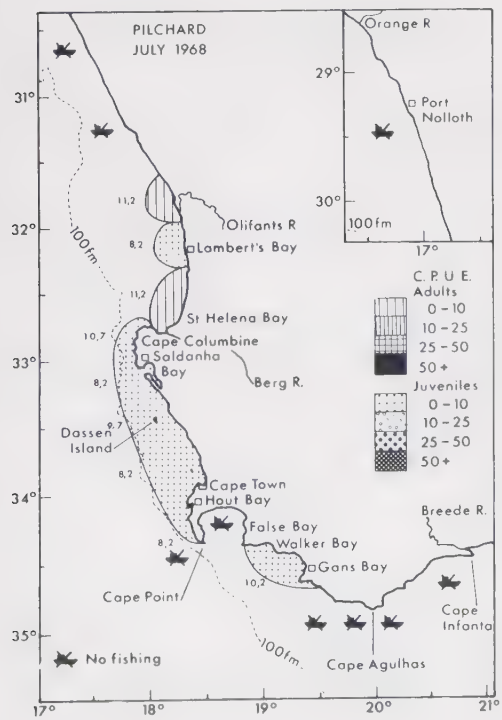
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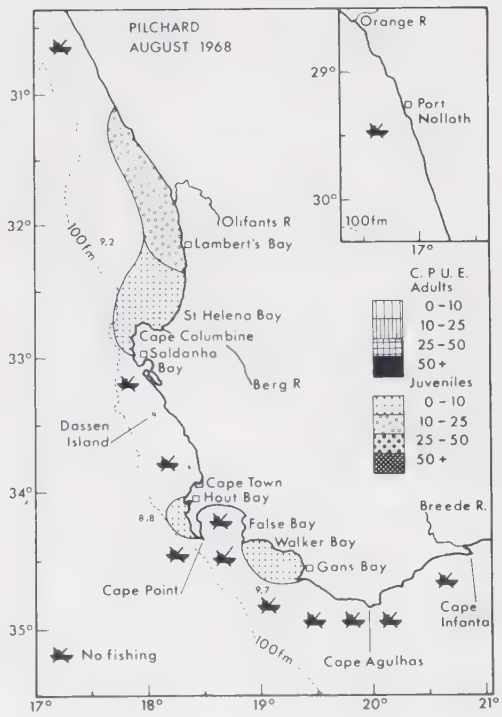
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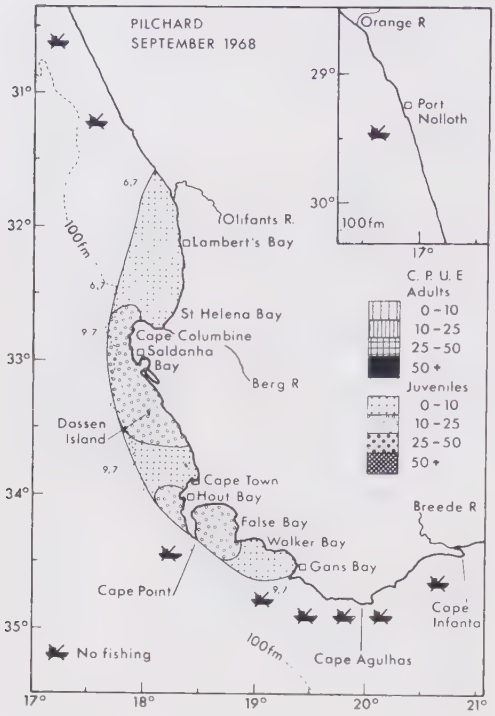
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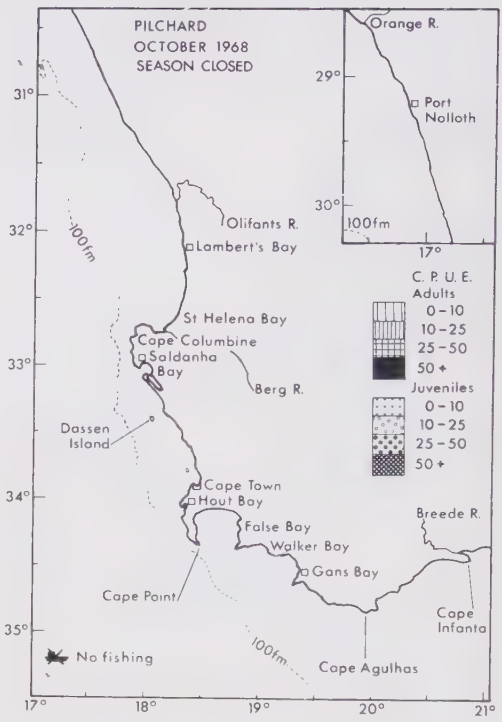
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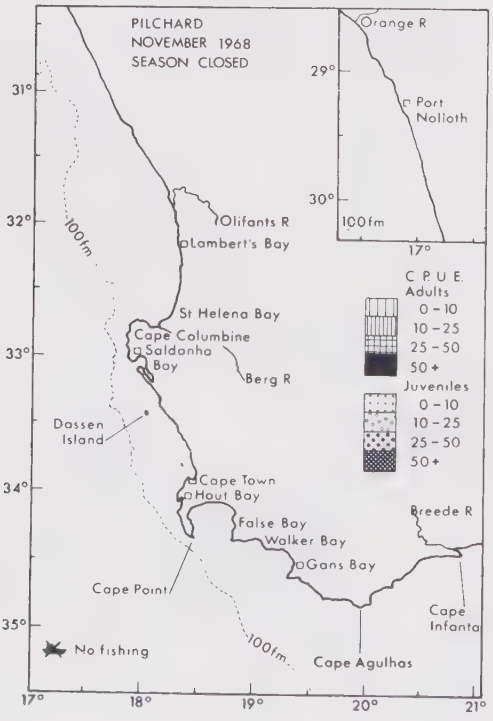
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Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Cape Point
Cape Agulhas
Breede R
Cape Infanta
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Juveniles
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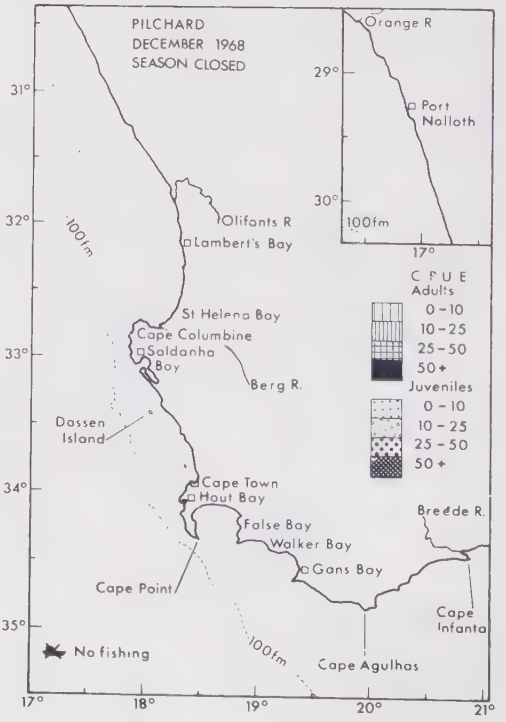
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Port Nolloth
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St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Cape Point
Cape Agulhas
Breede R.
Cape Infanta
No fishing
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Juveniles
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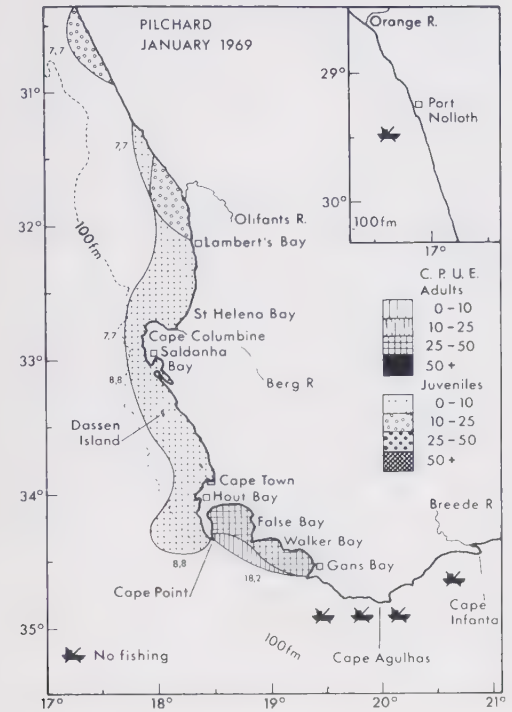
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Port Nolloth
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C. P. U. E.
Adults
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50 +
Juveniles
0 – 10
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25 – 50
50 +
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
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Gans Bay
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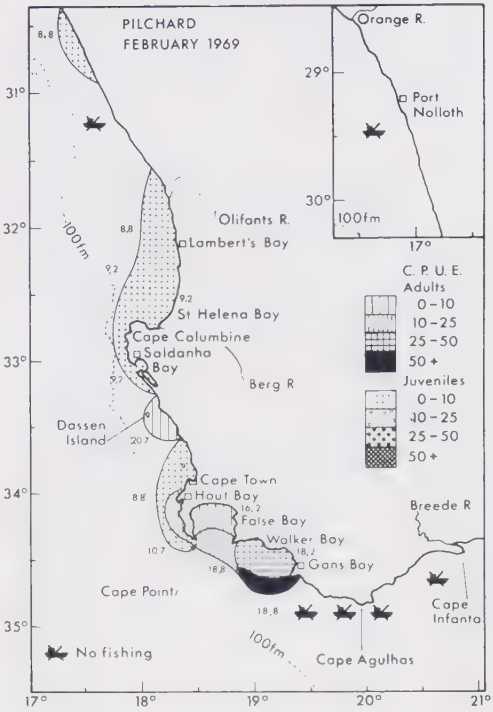
No fishing
100fm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Juveniles
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Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
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Cape Infanta
Cape Agulhas
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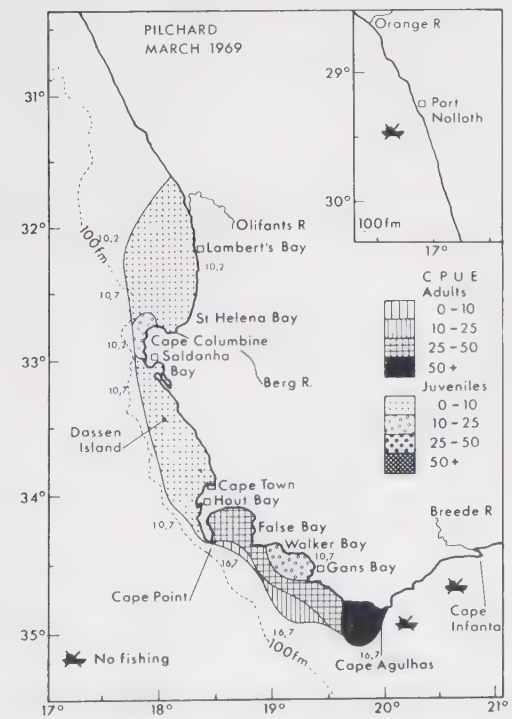
100fm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Adults
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Juveniles
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
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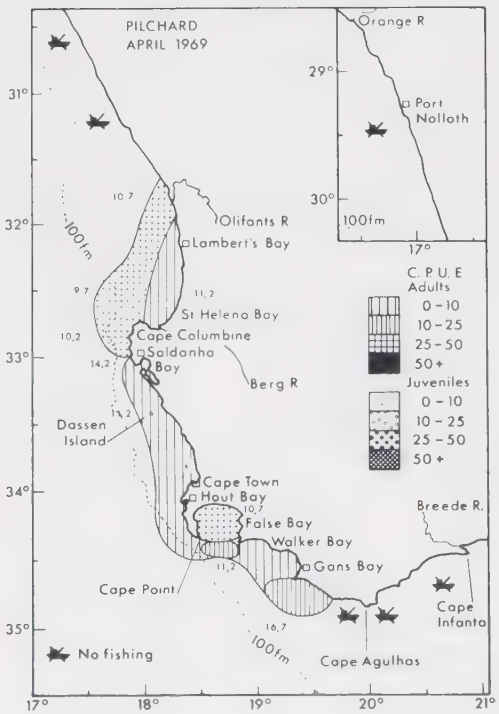
No fishing
100fm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Port Nolloth
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Adults
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Juveniles
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25 – 50
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Lambert's Bay
St Helena Bay
Cape Columbine
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Berg R
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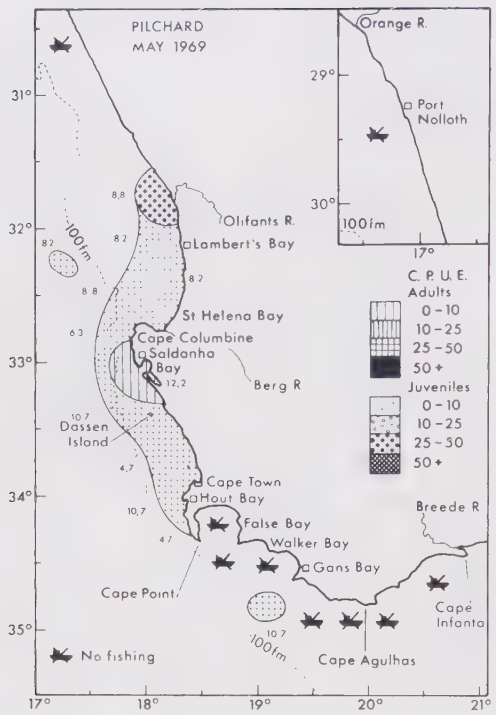
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Dassen Island
Cape Town
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Juveniles
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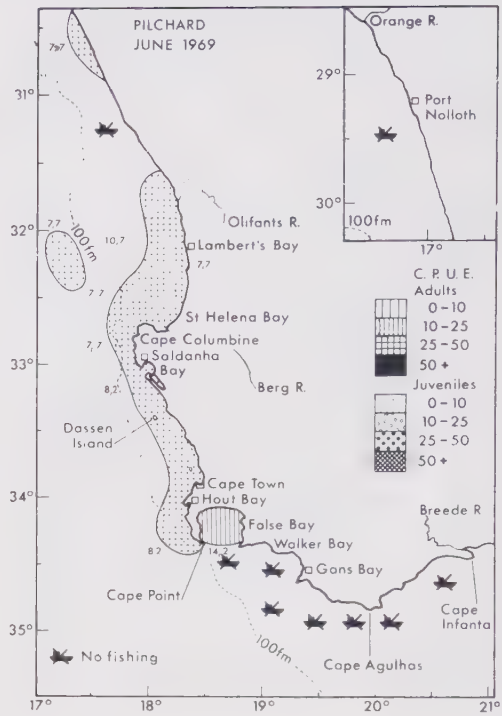
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Berg R.
Dassen Island
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No fishing
C. P. U. E.
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Juveniles
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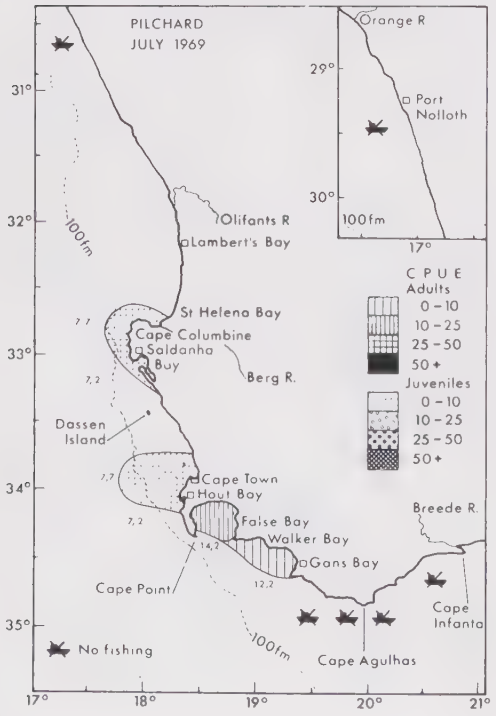
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Cape Town
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Juveniles
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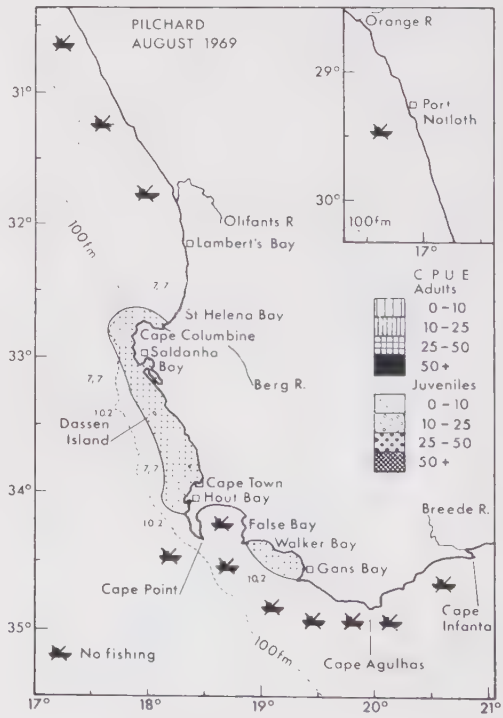
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Cape Town
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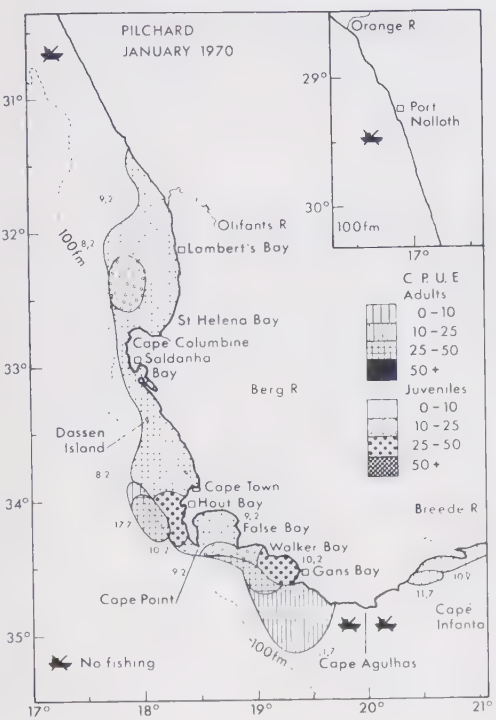
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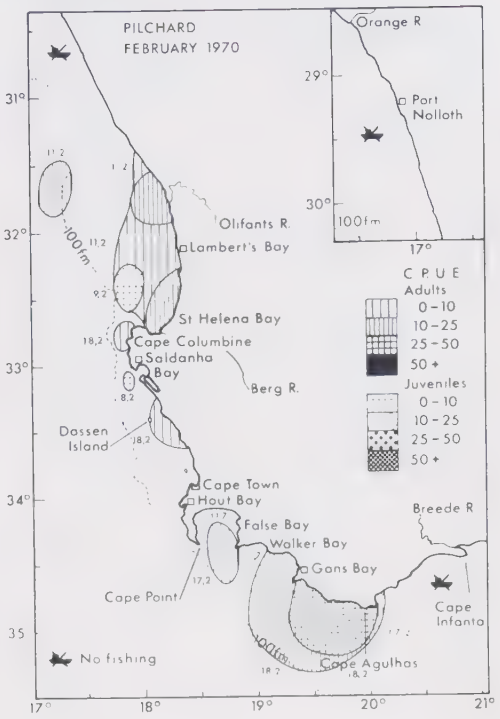
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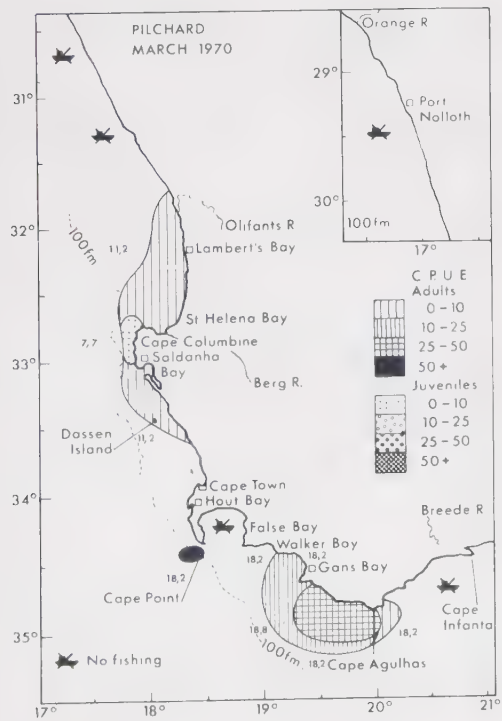
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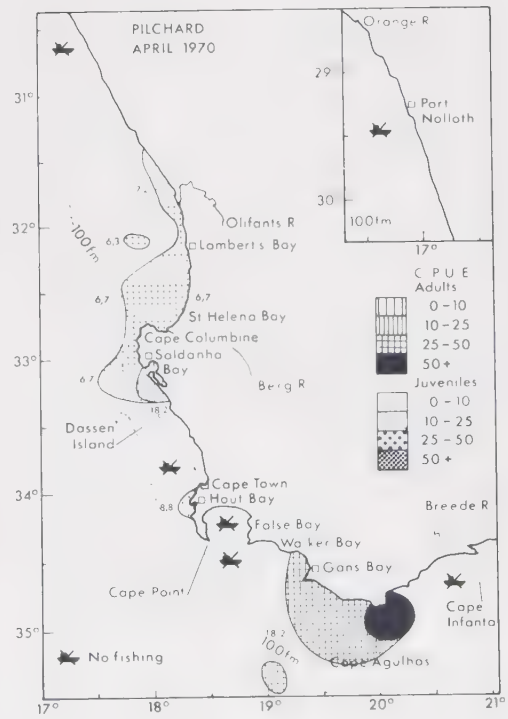
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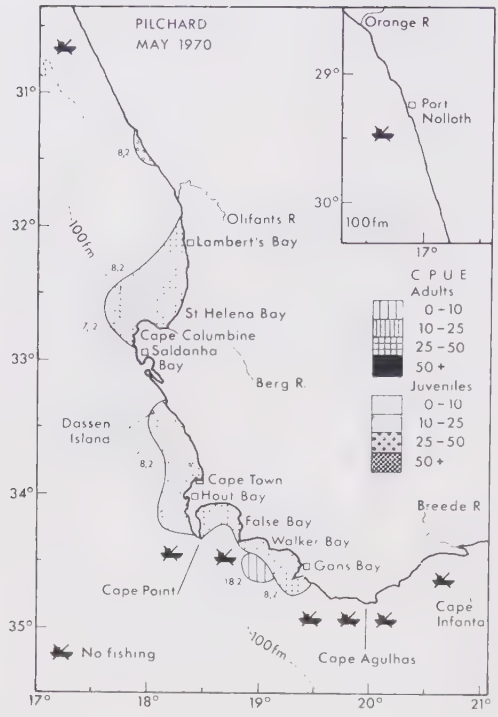
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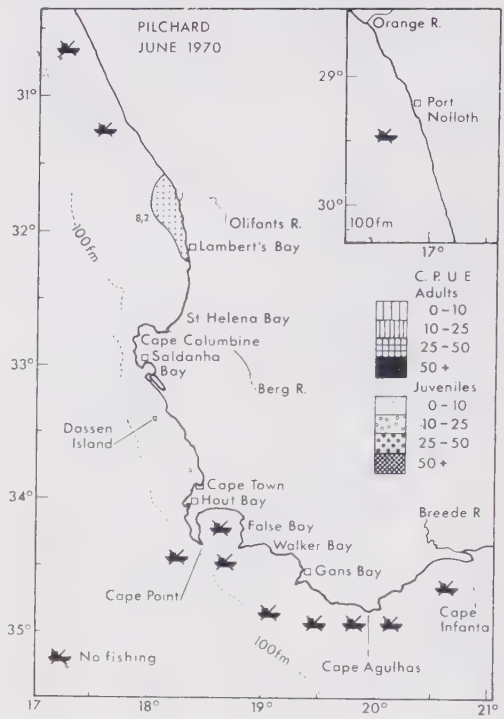
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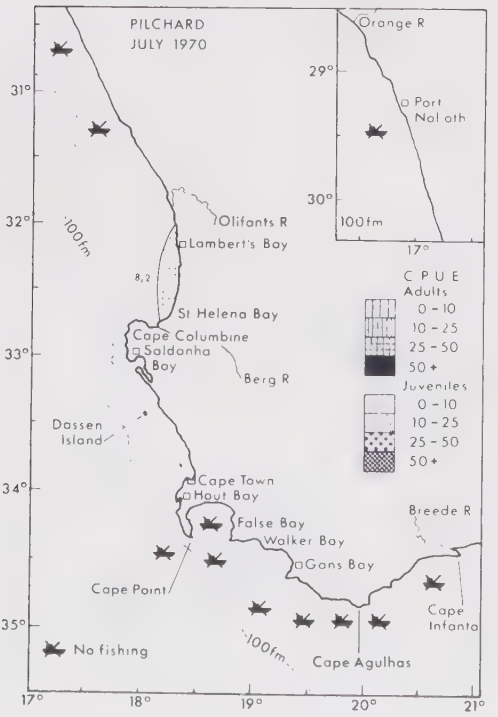
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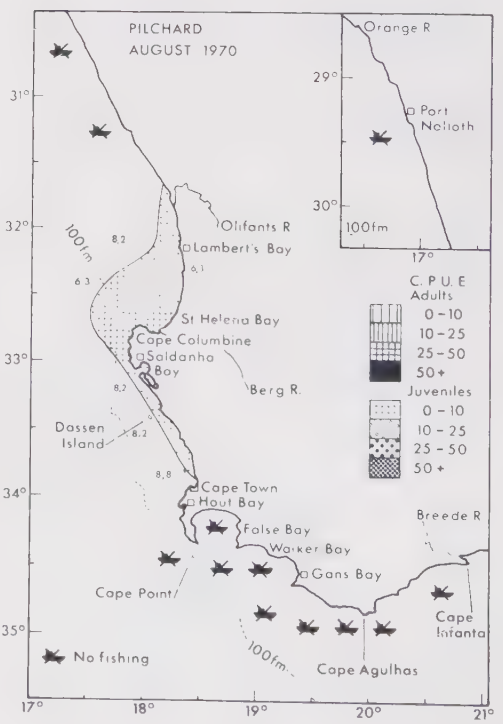
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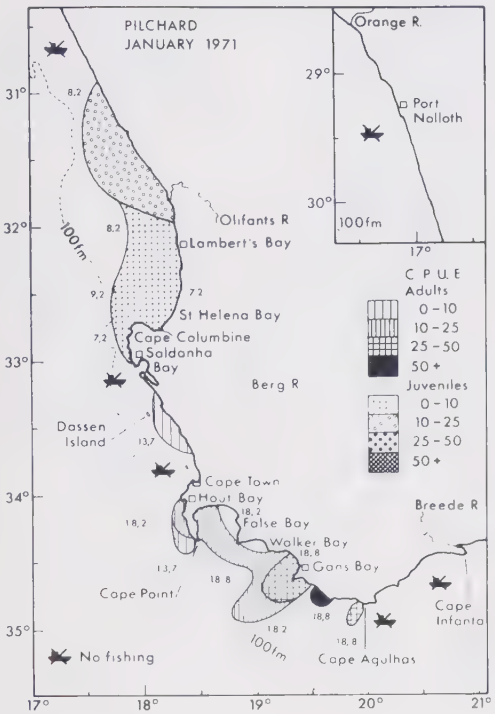
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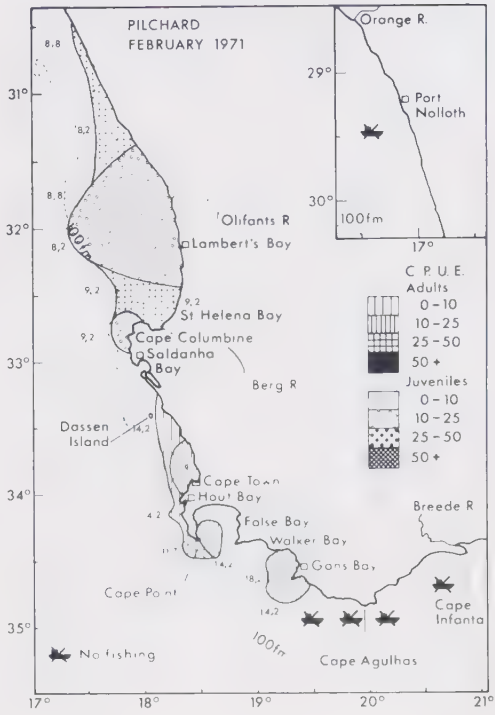
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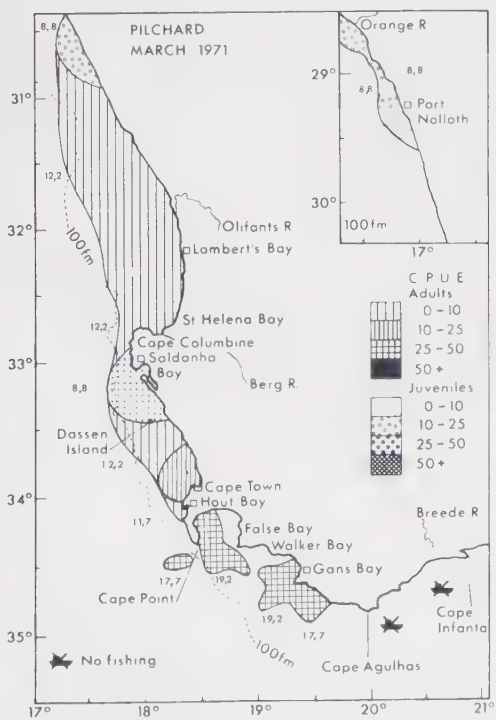
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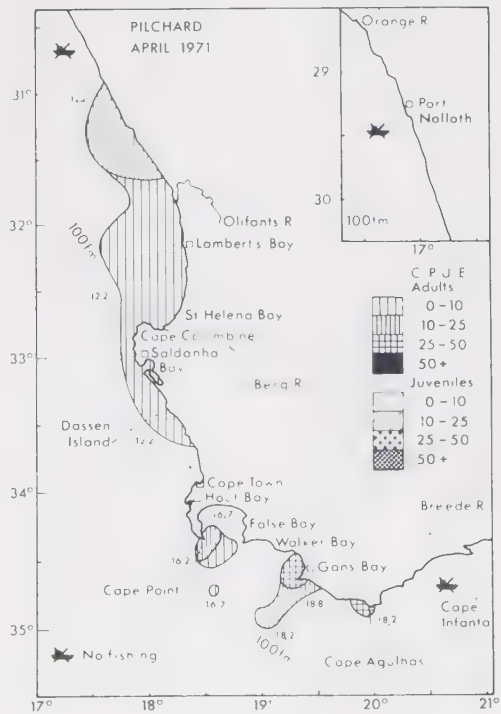
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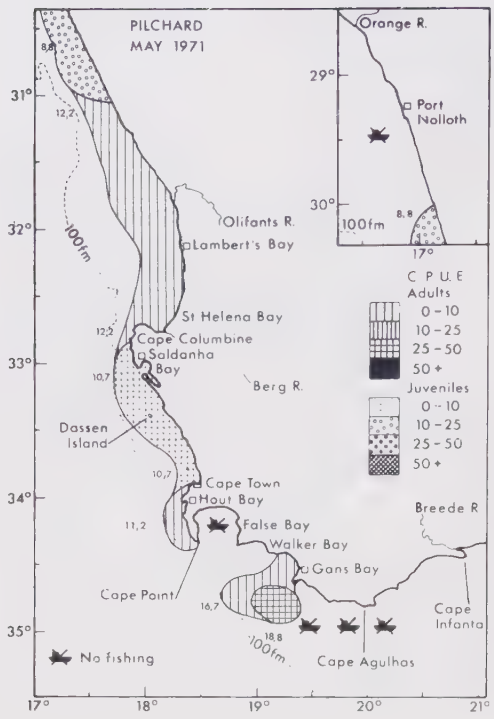
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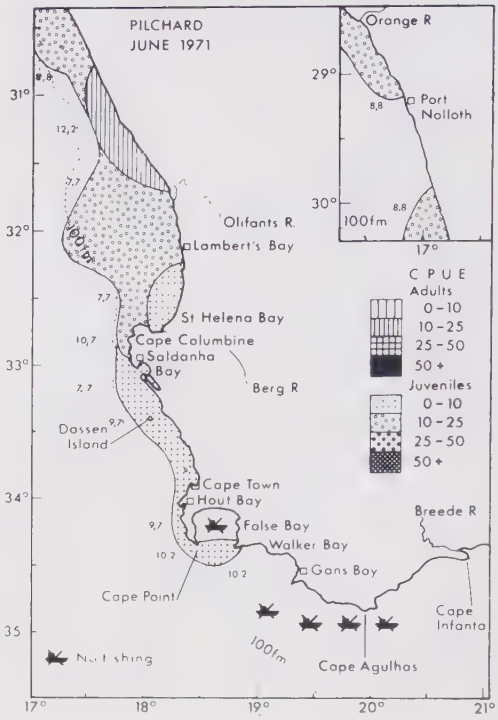
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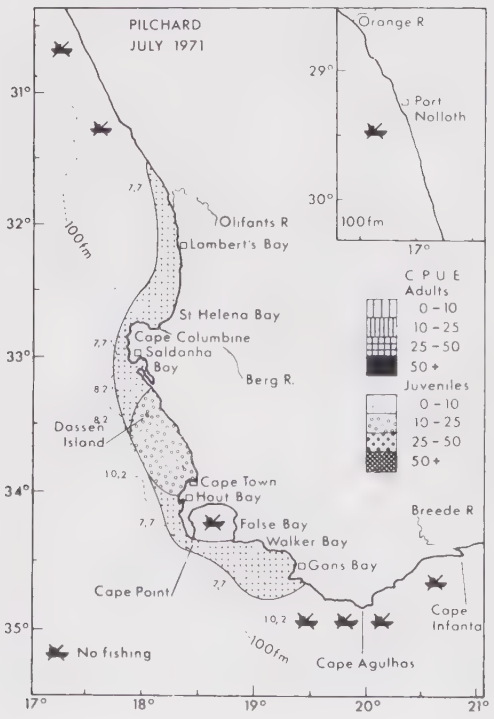
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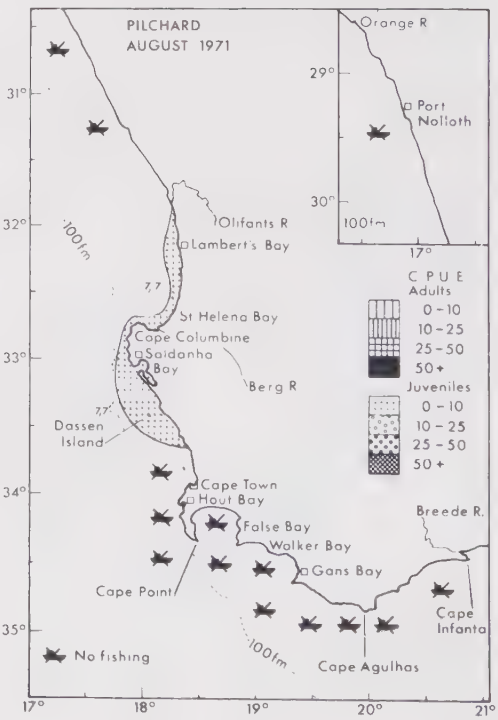
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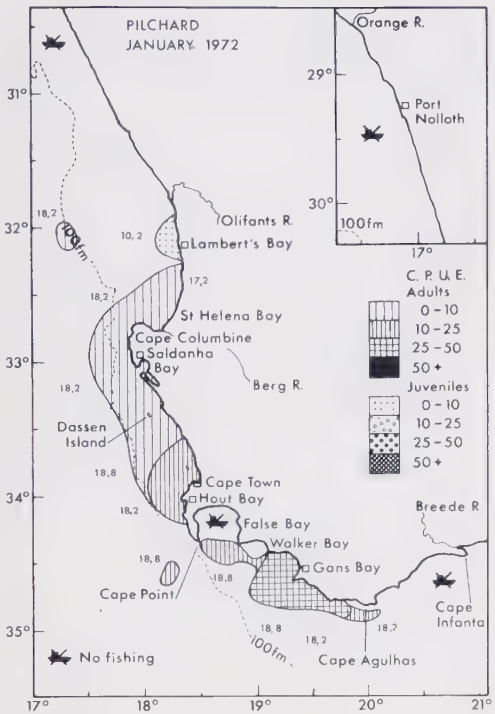
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Cape Point
Cape Infanta
Breede R
Cape Agulhas
No fishing
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Juveniles
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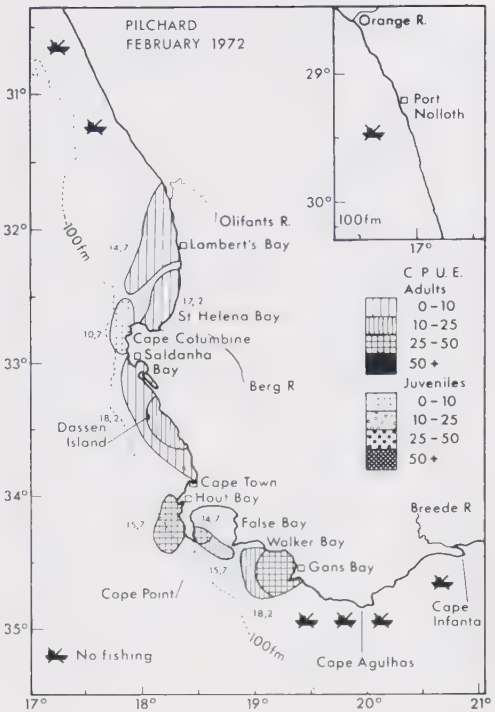
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Cape Point
Cape Infanta
Breede R
Cape Agulhas
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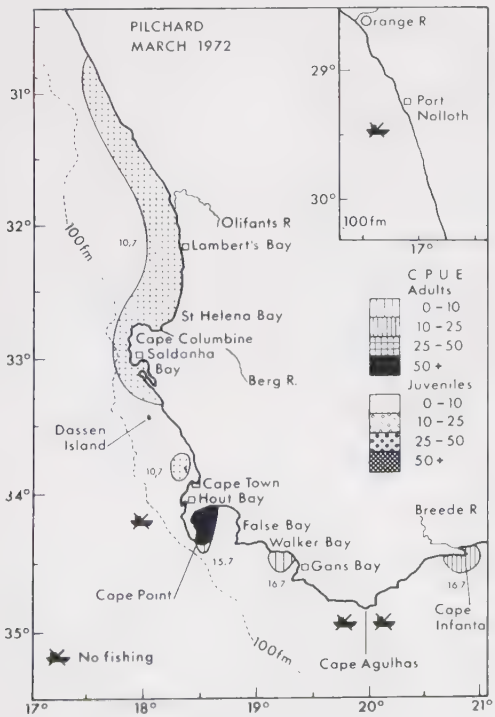
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Dassen Island
Cape Town
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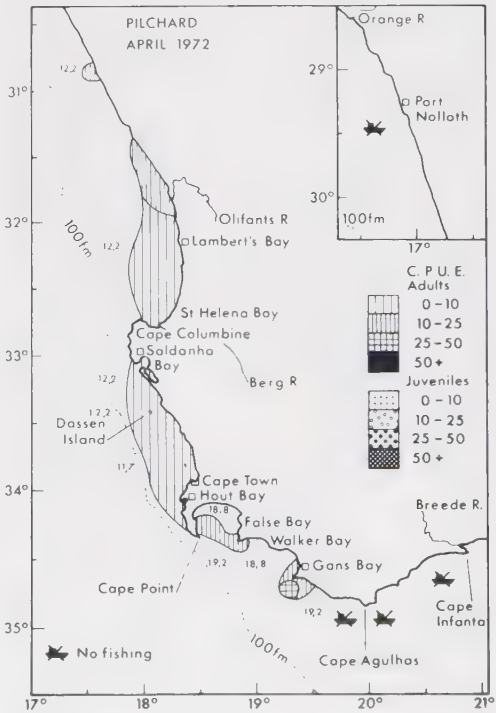
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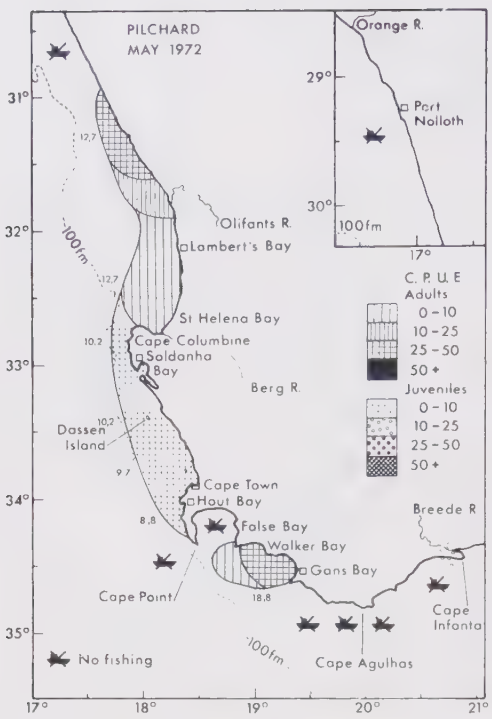
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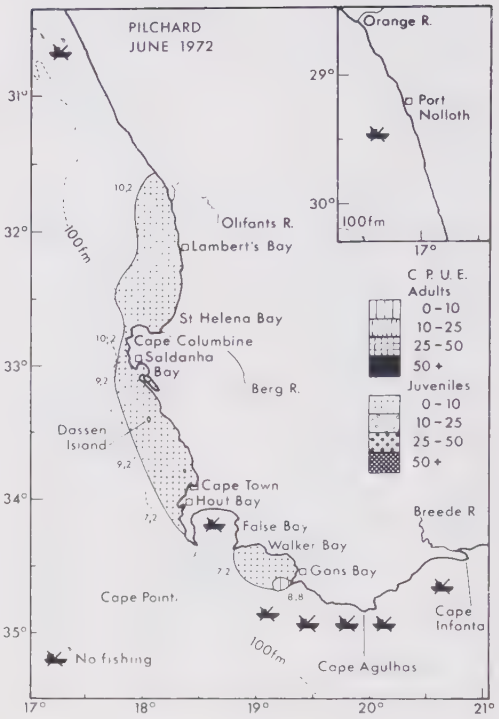
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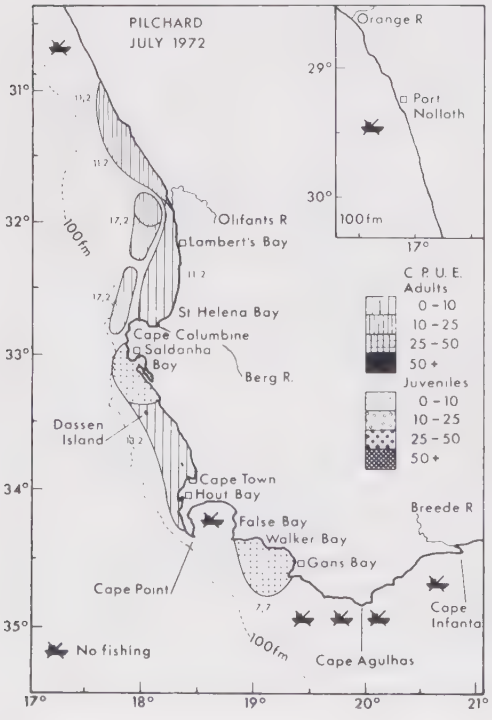
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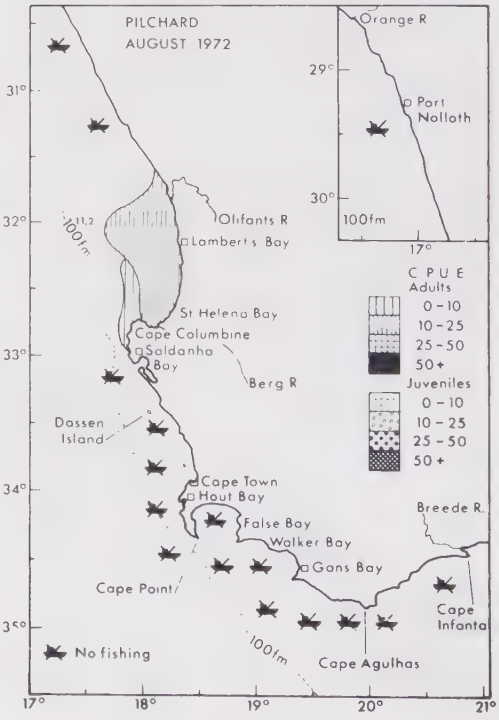
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Lambert's Bay
St Helena Bay
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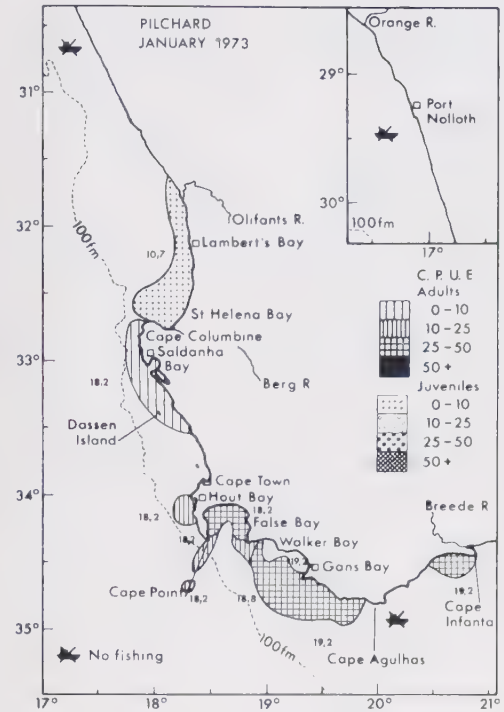
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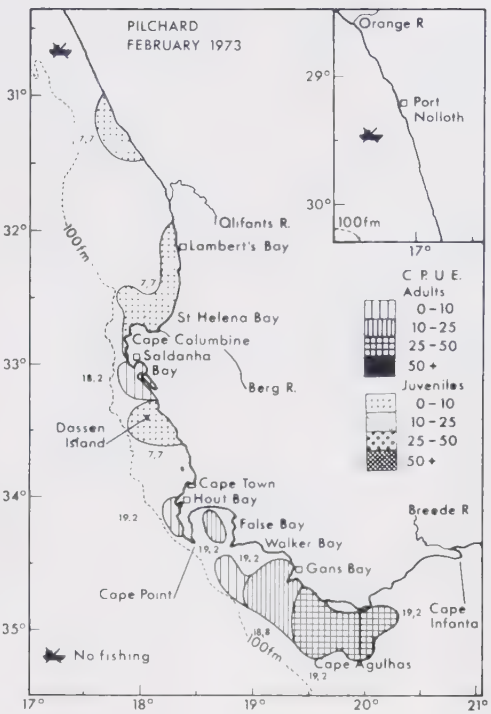
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Olifants R.
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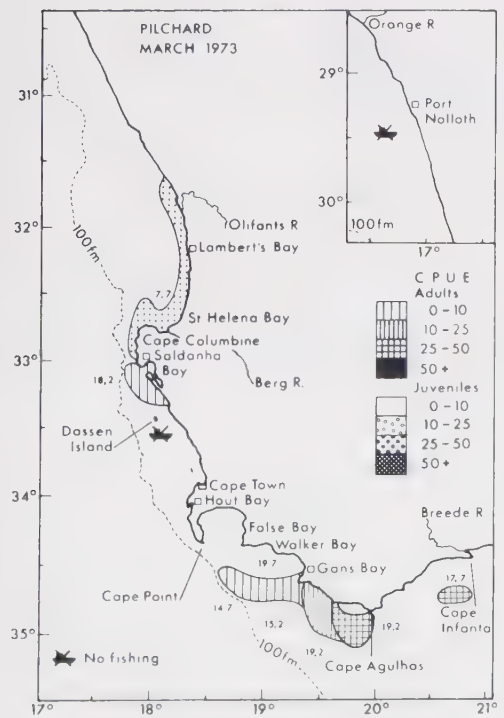
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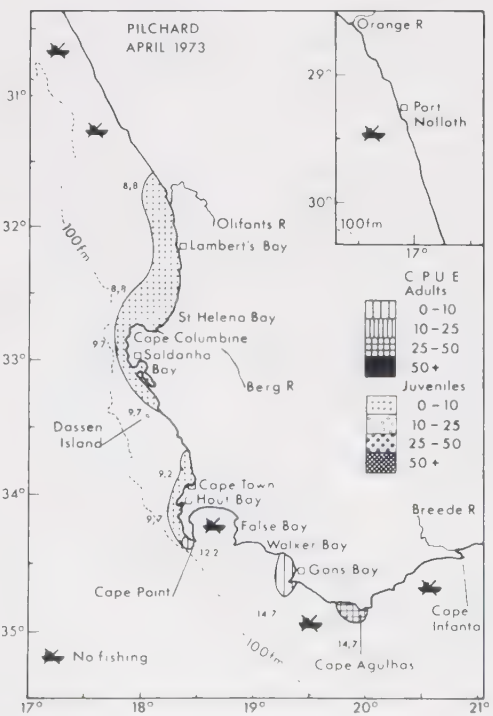
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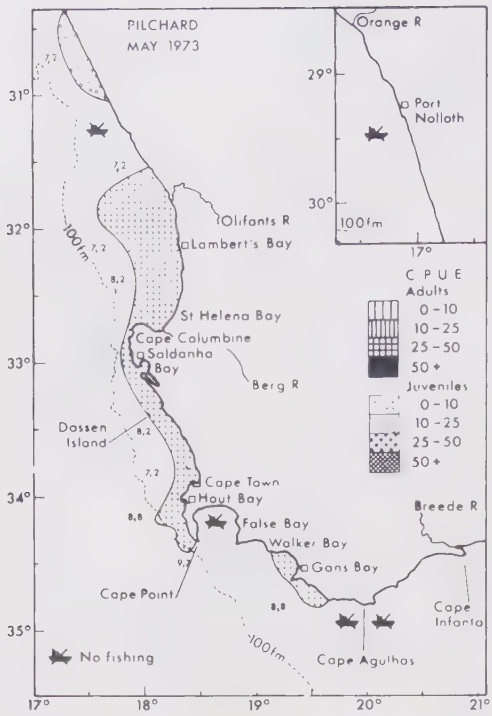
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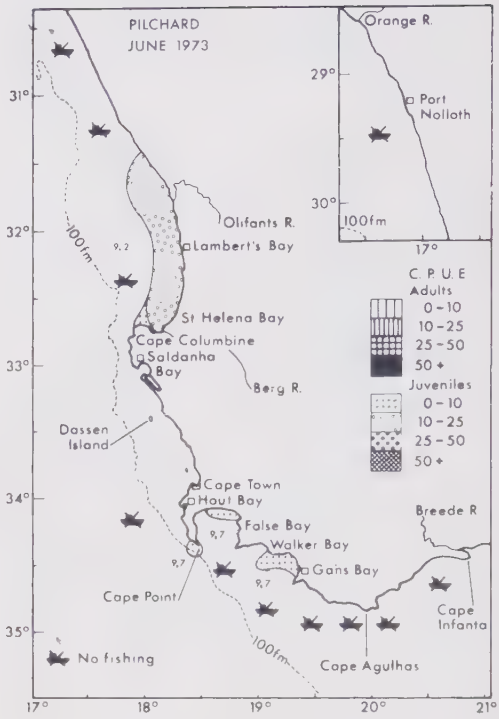
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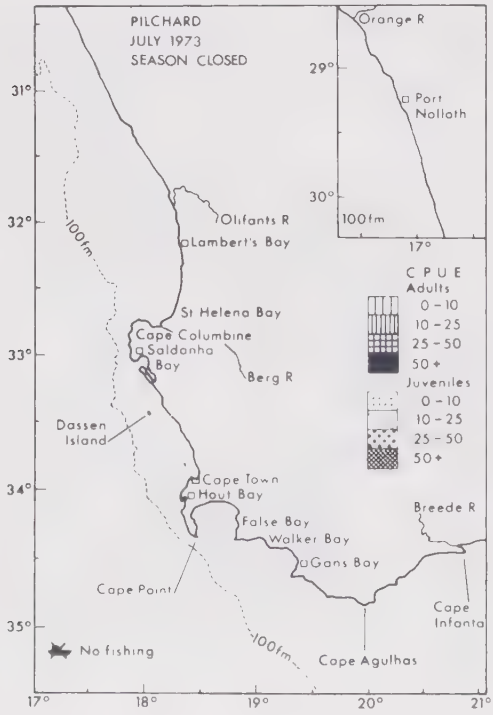
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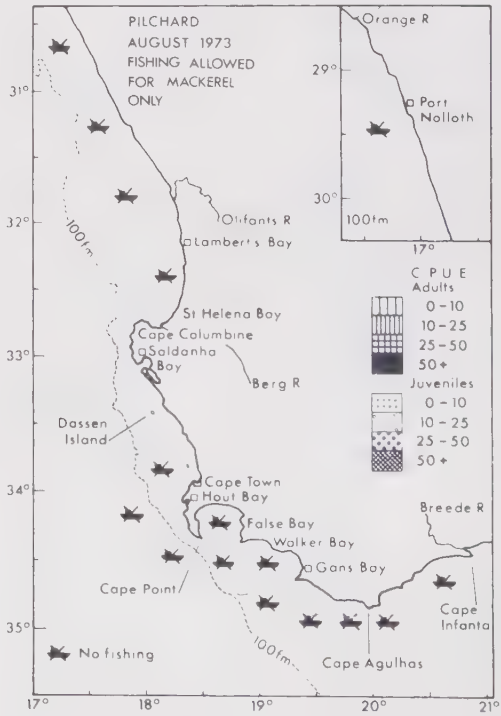
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FISHING ALLOWED
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Lambert's Bay
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Cape Columbine
Saldanha Bay
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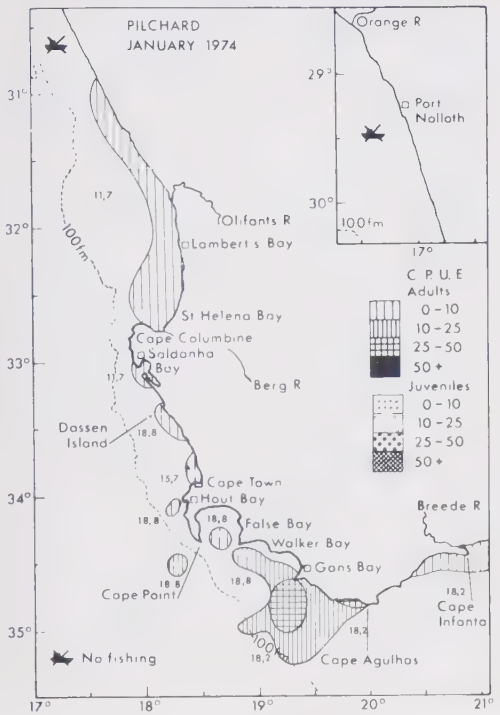
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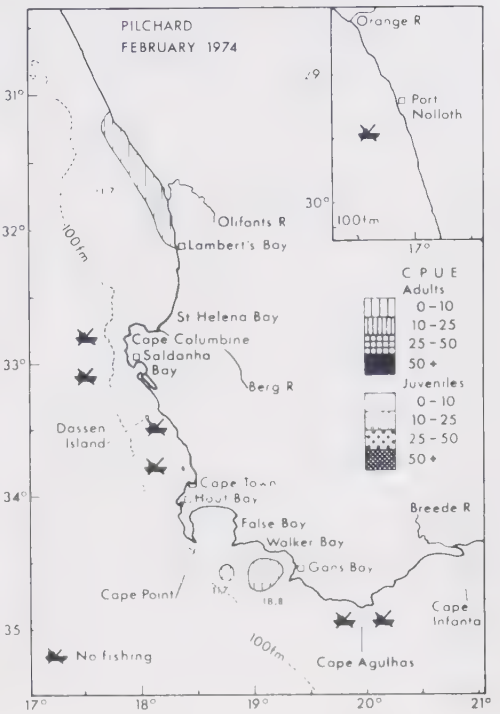
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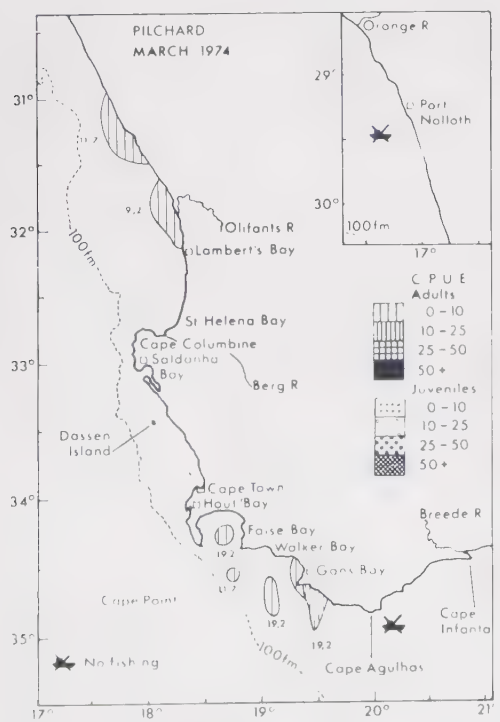
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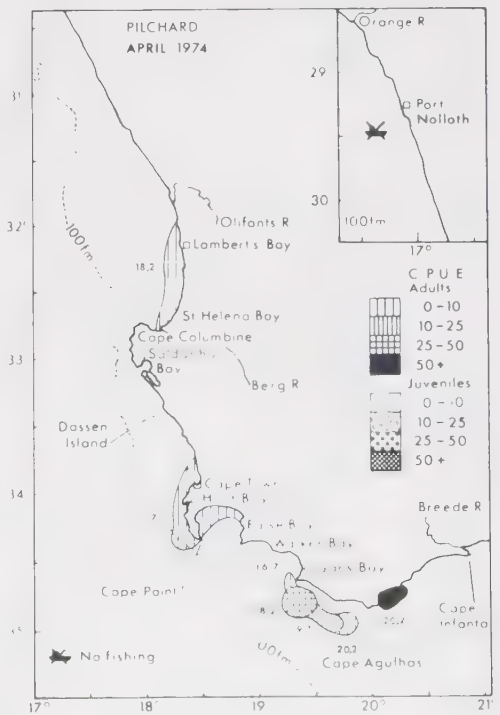
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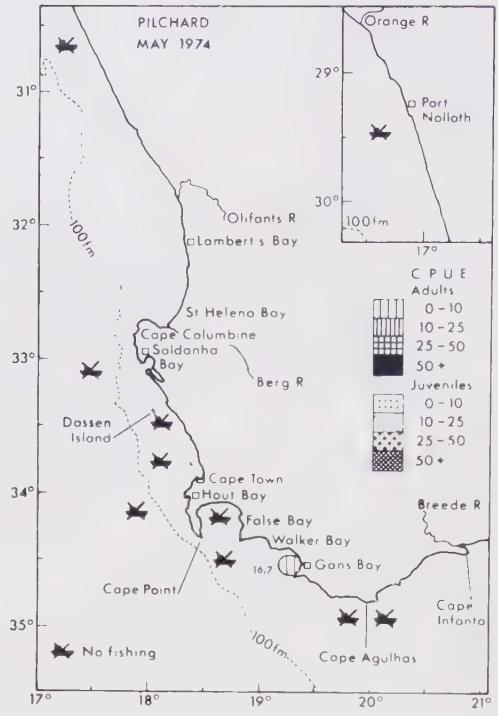
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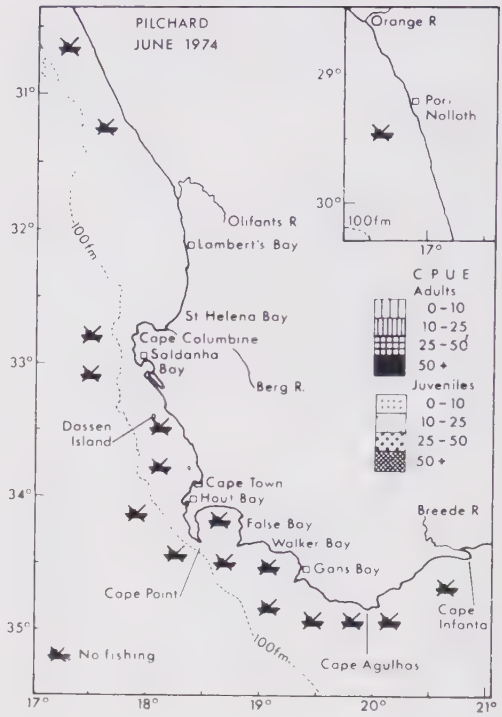
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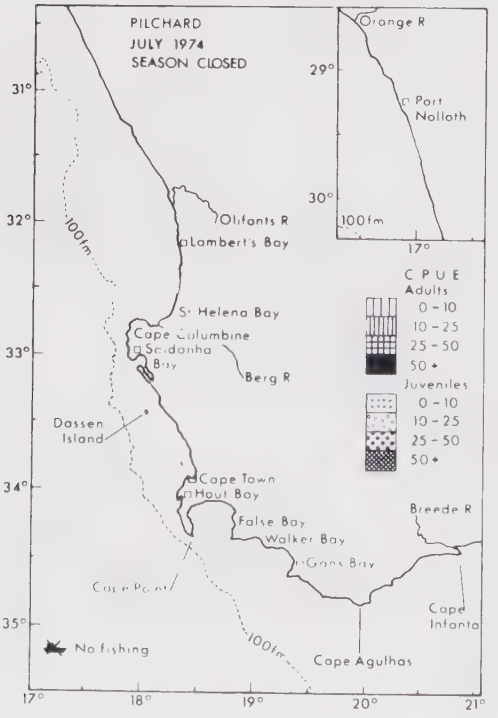
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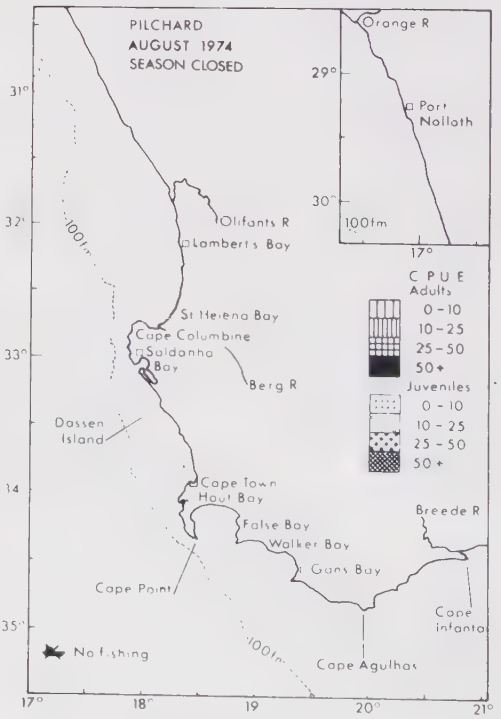
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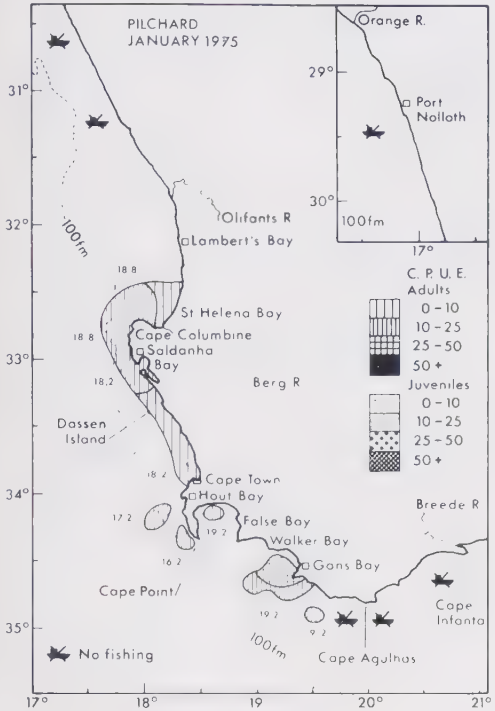
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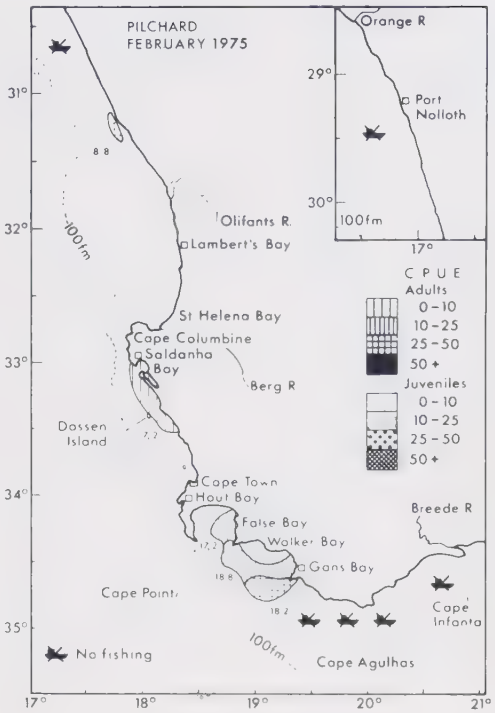
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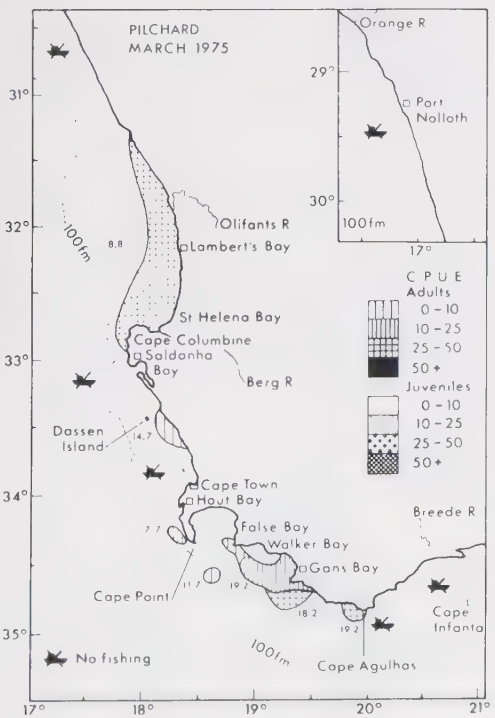
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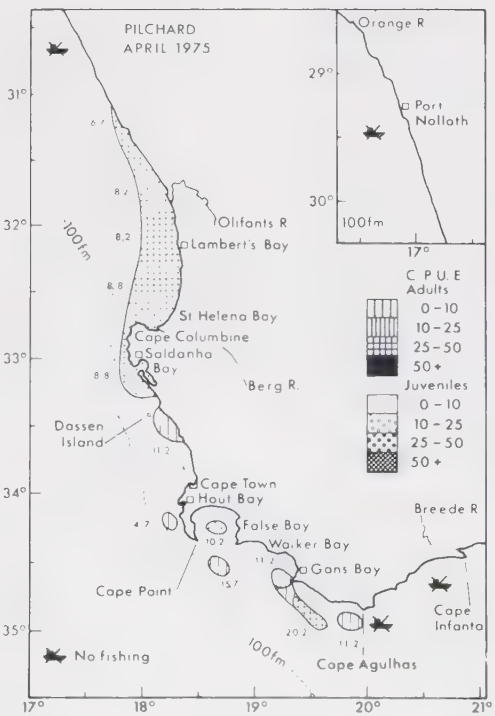
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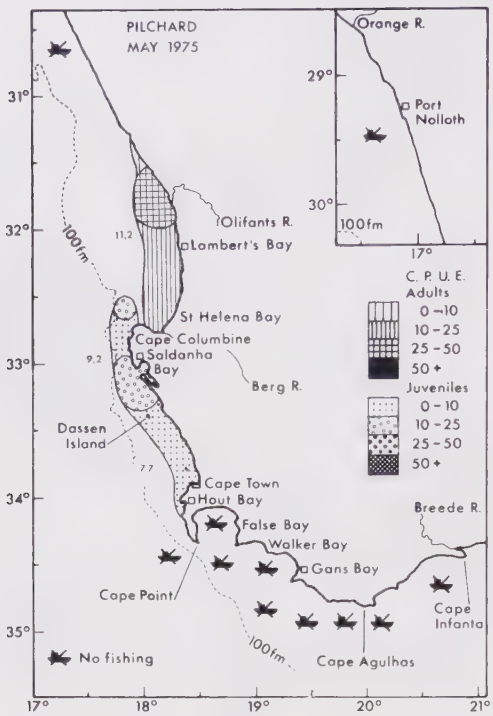
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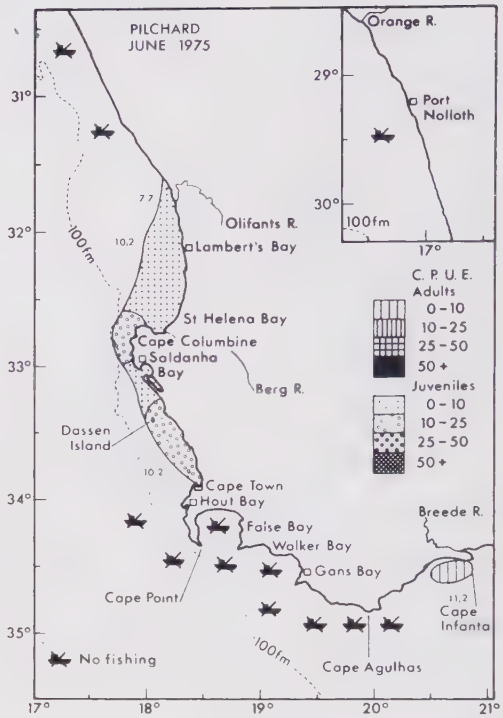
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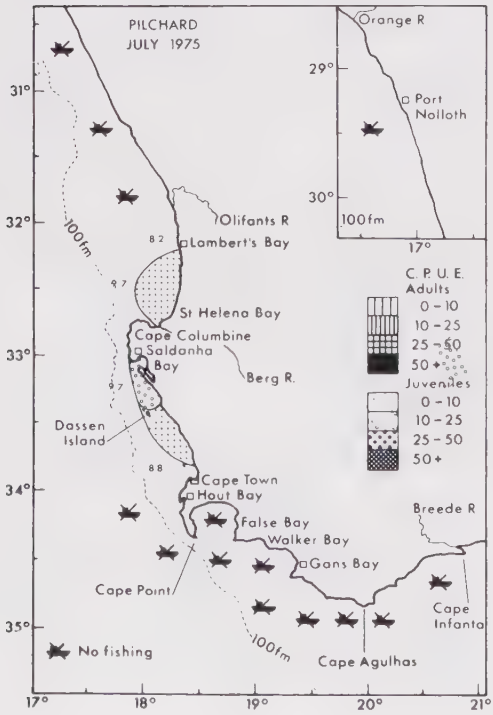
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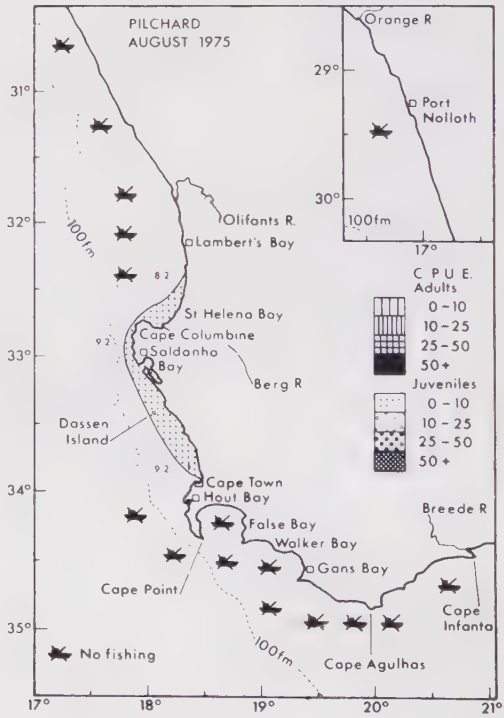
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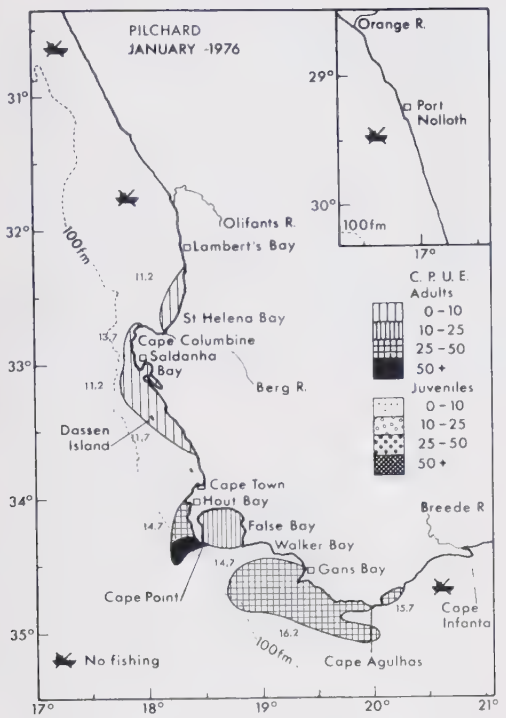
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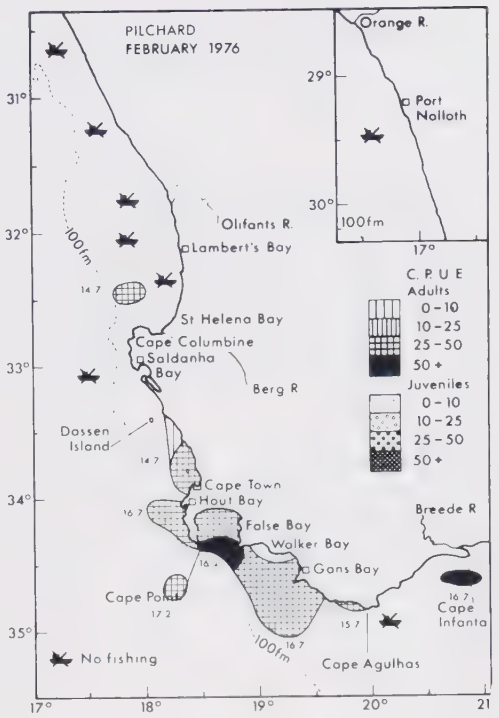
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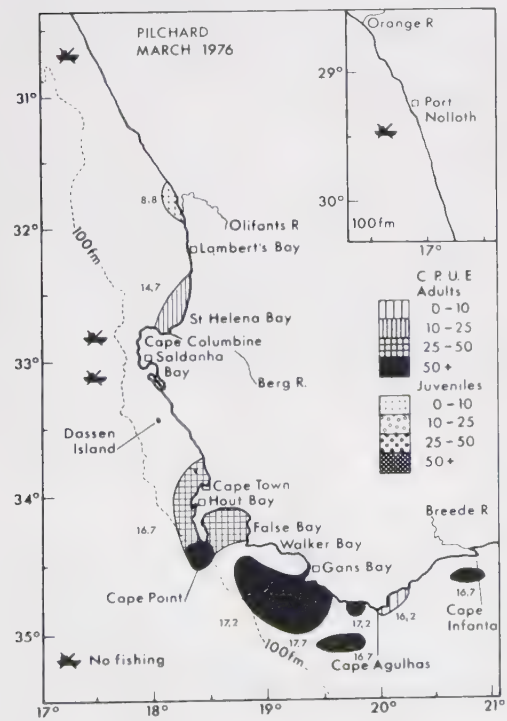
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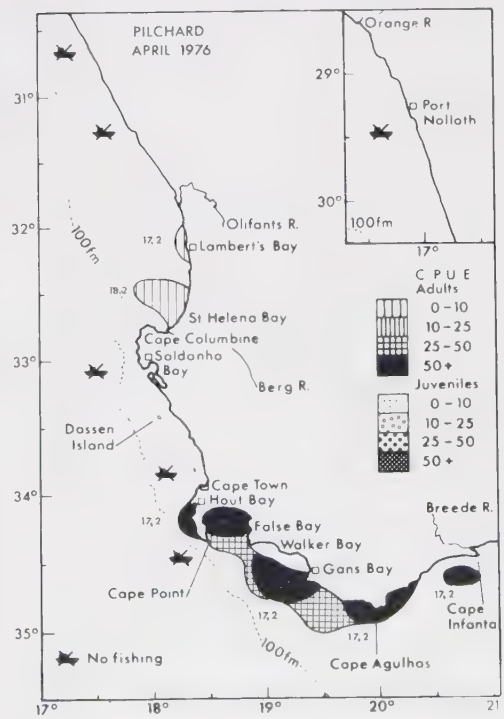
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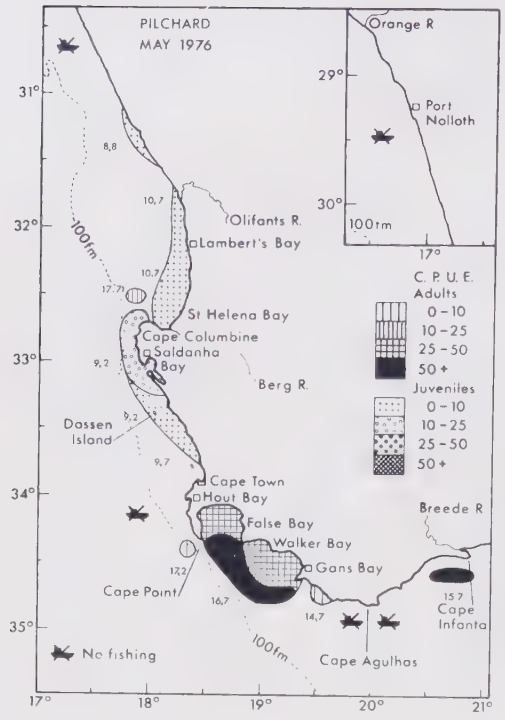
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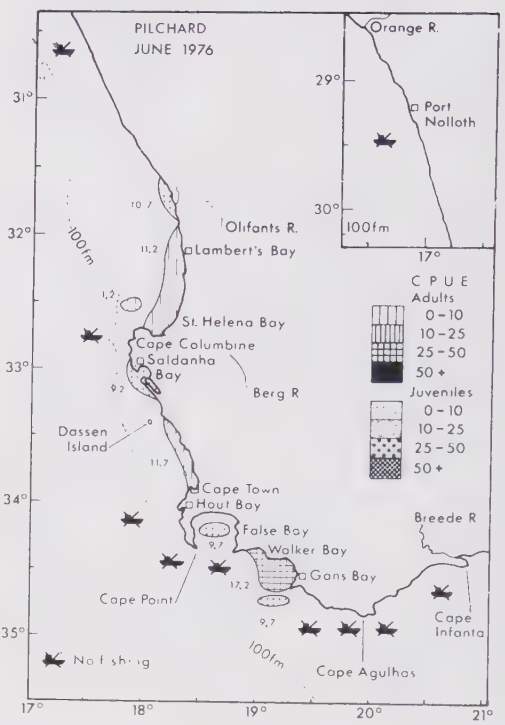
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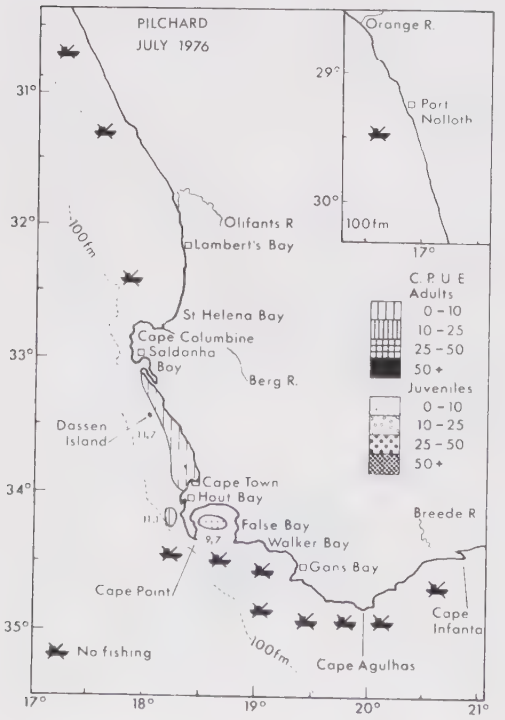
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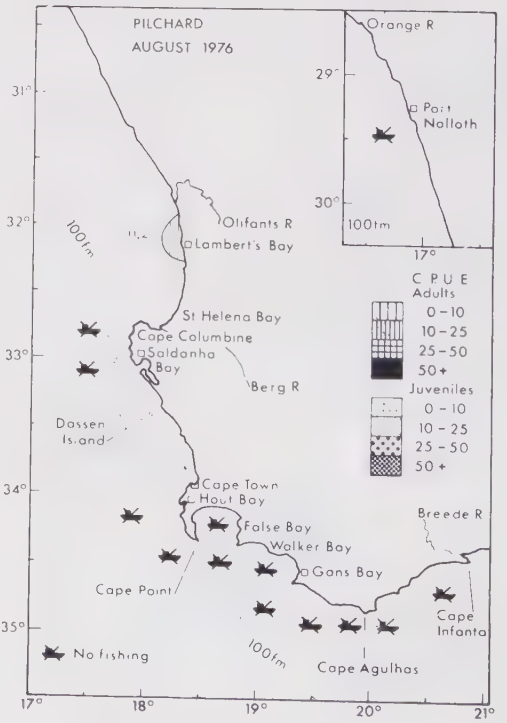
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A NOTE ON DIURNAL SPAWNING RHYTHM IN THE ANCHOVY *ENGRAULIS CAPENSIS* GILCHRIST

P. A. SHELTON and L. HUTCHINGS

In October 1976, a patch of newly spawned eggs of anchovy *Engraulis capensis* was followed for 68 hours by means of a drogue. Acoustic targets that formed a subsurface scattering layer at night, coinciding with nocturnal incidences of early-stage anchovy eggs in the plankton, were thought to be anchovy. The advantage of a diurnal spawning rhythm is discussed.

In Oktober 1976 is 'n kol pas gestorte eiers van die ansjovis *Engraulis capensis* 68 uur lank deur middel van 'n dryfanker gevolg. Akoestiese teikens wat snags 'n suboppervlak-verstrooiingslaag gevorm het, het saamgeval met die nagtelike voorkoms in die plankton van ansjoviseiers van 'n vroeë stadium, en is as ansjovis beskou. Die voordeel van 'n daaglikse kuitskietritme word bespreek.

Diurnal activity patterns in marine fish have en widely recorded (Richardson 1952, Inoue d Ogura 1958, Hela and Laevastu 1961, Holton 69). In general, adult fish have been shown to e towards the surface layers at sunset and to k into deeper waters at sunrise, and similar vements have been observed in fish larvae lliman 1943, Ahlstrom 1959, Miller *et al.* 1963, ith *et al.* 1978). A diel rhythm in the inflation of e swim bladder of *Engraulis mordax* larvae has en suggested by Hunter and Sanchez (1976) to an energy-saving mechanism facilitating vertical vement. The daily deposition of rings in the liths of larval and adult anchovy *E. mordax* others *et al.* 1976) may be explained by such tical movements made for feeding and other poses.

n addition to demonstrating the vertical migra- n of adult and larval fish, Ahlstrom (1959) nd that spawning in the Californian sardine *dinops caerulea* is confined to a limited part of night, usually between 20h00 and 24h00. erimposed on the diurnal migration and spawn- activity there may be a lunar periodicity as nd for *E. mordax* (Smith 1972).

Spawning activity in the South African anchovy *graulis capensis* was examined for diurnal pattern.

METHODS

A patch of eggs with concentrations of approxi- ately 200 eggs • 100 m^{-3} was located off Cape angklip on 28 October 1976. It was followed for period of 68 hours (Fig. 1) by means of a free- ifting parachute drogue, as part of an experiment transport of anchovy eggs and larvae (Shelton

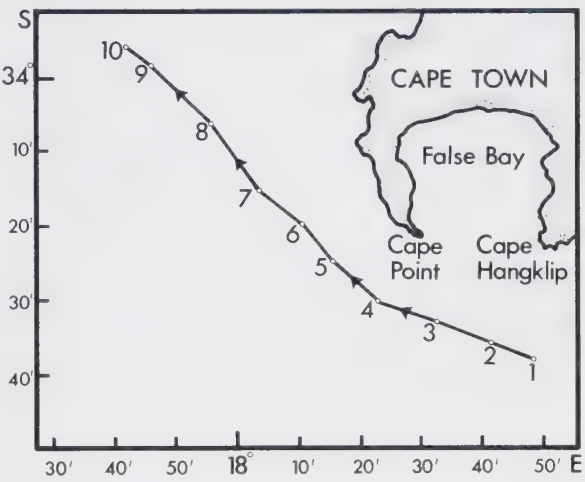


Fig. 1: The drogue path and stations sampled with Miller nets during October 1976

1979). The depth distribution of anchovy eggs was sampled at regular intervals (Stations 1 — 10, Fig. 1) by means of an array of eight Miller nets (Miller 1961) distributed between the surface and 85 m and towed at a speed of 3 knots for 60 minutes. In the laboratory, anchovy eggs were removed from the sample and those in the stage from fertilization to just prior to formation of the embryonic axis were counted and standardized to the number in 100 m^3 of water. Development from blastocap stage to blastopore closure (just after embryonic axis formation) takes approximately 25h at 16°C, the average temperature of the water above the thermocline where the eggs were found (King *et al.* 1978). Acoustic targets near the drogue were

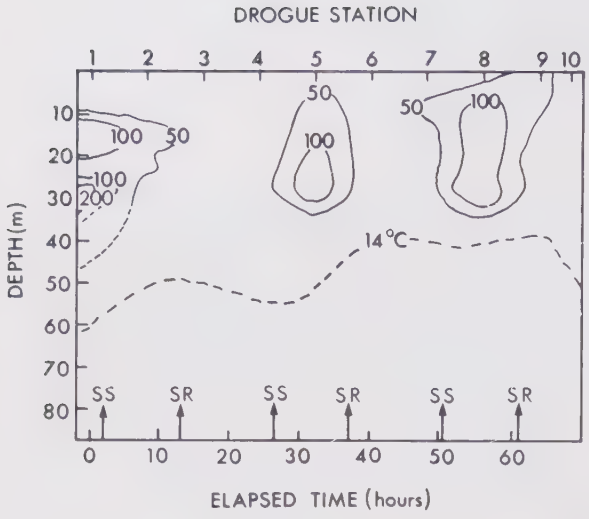


Fig. 2: The distribution by number per 100m³ of newly spawned anchovy eggs with time and depth at the drogue — the 14°C isotherm is shown by a broken line (SS = sunset, SR = sunrise)

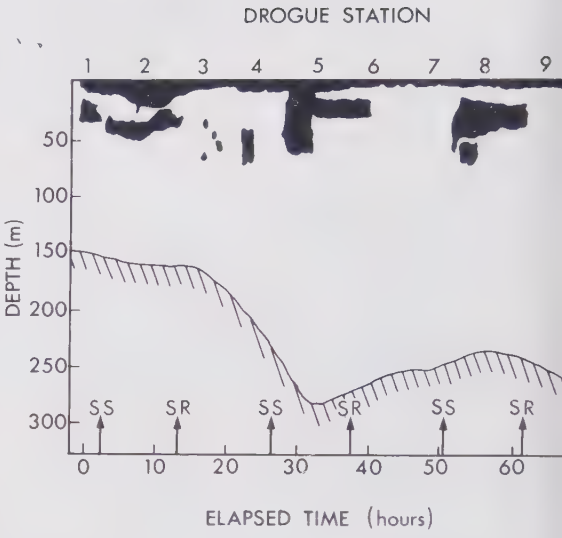


Fig. 3: A condensed echogram showing acoustic targe at the drogue

monitored continuously using a 200-kHz echo-sounder from the drifting ship.

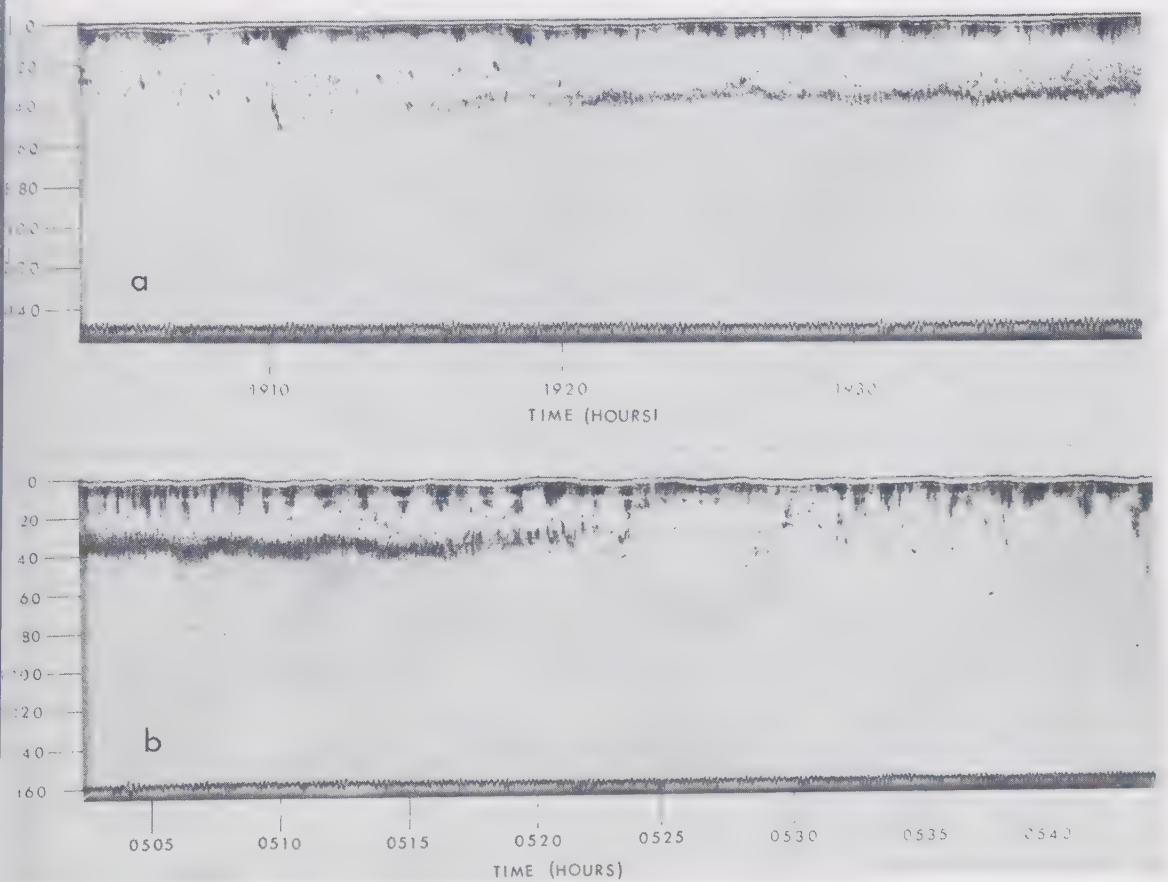
RESULTS

Interpolation between stations provides evidence of a nocturnal spawning rhythm during the second and third nights, although early-stage eggs were abundant before sunset of the first night (Fig. 2) and present in low numbers at all stations. Egg production occurred above the 14°C isotherm, which represented the middle of a thermocline layer present at all stations. King *et al.* (1978) found that normal development of the egg and early larva was inhibited at temperatures below 14°C.

The condensed continuous echogram along the drogue path (Fig. 3) shows a regular surface-scattering layer which may be attributed to turbulence at the hull of the ship. Acoustic targets formed large subsurface layers corresponding in depth and duration to the occurrence of early-stage anchovy eggs, and they are thought to have been shoals of spawning adult anchovy forming rapidly at sunset and dispersing at sunrise (Fig. 4). However, plankton samples showed that, at most of the stations, the dominant zooplankton organism was *Euphausia lucens,* and this species may have contributed to the scattering layer. A midwat trawl was not available to positively identify th echo.

DISCUSSION

There are obvious advantages for the Sou African anchovy in spawning nocturnally. Und the cover of darkness fish can congregate in lar shoals to facilitate fertilization of the ova, with reduced threat of a heavy mortality being inflicte by predators such as snoek *Thyrsites atun,* Ca fur seal *Arctocephalus pusillus* or sea birds whi rely on visual acuity to capture their prey. Hobs and Chess (1978) found seven times more plankton fish eggs over nearshore reefs at night than duri the day. They speculated that spawning early the night would be highly adaptive because t eggs would have maximum time for dispersing the dark, relatively free from planktivorous re fish. Should adult *E. capensis* be particulate feede as recorded for *E. mordax* in the laboratory b Leong and O'Connell (1969), then it is possib they would also ingest their own eggs. If so, the darkness would restrict cannibalism. Also, if shoa of fish that spawned near the surface in the da moved into deeper water at sunrise, they wou be separated from the eggs when feeding partic



4: Echograms showing (a) formation of an anchovy shoal at sunset and (b) dispersal of the shoal at sunrise — the trace was obtained from the drifting ship in the vicinity of the drogue on 29 and 30 October 1976, and sunset was at 19h10 and sunrise 05h48

ely.

Time from fertilization to hatching at 16°C is proximately 45h (King *et al.* 1978). Therefore, this temperature hatching would also take place the dark, a further survival advantage, because he yolk-sac larva is particularly vulnerable as it truggles to break out of the chorion.

Future observations on the spawning rhythm of he anchovy should be made over a number of ights and should be repeated during different arts of the lunar cycle.

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DISTRIBUTION, AVAILABILITY AND MOVEMENTS OF ANCHOVY *ENGRAULIS CAPENSIS* OFF SOUTH AFRICA, 1964–1976

R. J. M. CRAWFORD

Exploratory fishing for anchovy *Engraulis capensis* by means of small-meshed (12,7-mm) nets and vessels equipped with power blocks was initiated in 1963. Large catches were recorded in 1964 and, from 1966, the species has consistently been the most important contributor to the South African purse-seiner landings. Most catches have been recorded inside the 200-m bottom contour, fish usually shoaling according to size. Spawning is largely confined to the period October – January, with eggs occurring in their densest concentrations in the warmer waters east of Cape Point. The ichthyoplankton subsequently disperses into the Benguela Current system, where spring and summer upwelling assures an abundant food supply for these early stages. In late autumn or early winter juveniles recruit to the fishery in their highest numbers on the northern grounds. Some anchovies mature at the end of their first year, and at the advent of spring return towards the southern spawning region. After spawning, adults frequently move out of the fishing grounds in an easterly direction, although good hauls have been recorded off the West Coast in winter. The distribution pattern of adult anchovy is less regular than that of pilchard *Sardinops ocellata*, and the currently greater relative abundance of anchovy, as shown by the change in the fishery from dependence primarily on pilchard (1950–1965) to domination by anchovy, has proved particularly detrimental to one of the major predators, the jackass penguin *Spheniscus demersus*, which, being flightless, needs a predictable food source.

In 1963 is daar begin met toetsvangste van anjovis *Engraulis capensis* deur middel van fynmaasnette (12,7 mm) en vaartuie met kragblokke toegerus. Groot vangste is in 1964 opgeteken en, sedert 1966, lewer die spesie die grootste bydrae tot die Suid-Afrikaanse beursnetvangste. Vangste is meesal binne die 200-myl-bodemkontoer opgeteken en saamskoling geskied gewoonlik volgens grootte. Kuitskieting is hoofsaaklik tot die tydperk Oktober - Januarie beperk, met die digste eierkonsentrasies in die warmer waters oos van Kaappunt. Vervolgens versprei die igtioplankton na die Benguelastroomstelsel, waar die lente- en someropwelling hierdie vroeë stadiums van 'n ryk voedselvoorraad verseker. Laat in die herfs of in die voorwinter tree die grootste hoeveelheid jong rekrute tot die vissery toe op die noordelike gronde. Sommige ansjovis bereik geslagsrypheid aan die einde van hul eerste jaar, en met die aanbreek van die lente keer hulle na die suide terug om kuit te skiet. Ná kuitskieting beweeg geslagsrypes dikwels uit die visgronde ooswaarts, hoewel daar al langs die Weskus goeie wintervangste opgeteken is. Die verspreidingspatroon van geslagsryp ansjovis is wisselvalliger as dié van sardyn *Sardinops ocellata*, en die huidige groter relatiewe talrykheid van ansjovis soos blyk uit die verandering in die vissery – van afhanklikheid in die eerste plek van sardyn (1950–1965) tot oorheersing deur ansjovis – het veral 'n nadelige uitwerking gehad op een van die vernaamste roofvyande, die Kaapse pikkewyn *Spheniscus demersus* wat, omdat dit nie kan vlieg nie, 'n voorspelbare voedselbron nodig het.

The latent economic potential of the anchovy *Engraulis capensis* in South African waters was first recognized by Gilchrist (1913), who brought it to "... the attention of fishermen and fish merchants", noting that it provided "... an opening for fishery enterprise." However, it was not until some fifty years later that catches of this species were to assume any real importance (Table I).

Upon its inception in 1943, the South African purse-seine fishery was largely pre-occupied with exploitation of the pilchard *Sardinops ocellata* and horse-mackerel *Trachurus trachurus* resources (Du Plessis 1959), and these two stocks continued to dominate the landings until the early sixties. In particular, exceptionally strong 1956, 1957, 1958 and 1959 pilchard year-classes (Newman and Crawford 1980) led to considerable increases in fishing effort, and total catches in excess of 400 000 metric tons were recorded. Subsequently, when recruitment returned to more normal levels, it was not possible to maintain these yields and managers of processing plants sought alternative resources to bolster their diminishing returns.

With this in mind exploratory fishing for anchovy was initiated in 1963, during the closed season for pilchard, with the co-operation of the Fisheries Development Corporation. From September six boats were equipped with small-meshed (12,7-mm) nets and power blocks, but it took several months for skippers to master the operation of this new gear and it was not until December, when 282 tons were landed, that the experiment started to provide encouraging results. The January opening of the 1964 season resulted in a further delay, because the six skippers preferred to concentrate on the traditional pilchard resource, but in April they again recorded large catches of anchovy, up to 100 tons for a single haul, and it was soon

Table I: Landings of anchovy and their contribution to the total South African purse-seine catch, 1958-1976*

Year	Landings (metric tons)	Proportion of total combined landings (%)
1958	172	0,1
1959	1 375	0,4
1960	—	—
1961	—	—
1962	—	—
1963	282	0,1
1964	92 437	21,7
1965	171 014	35,6
1966	143 916	40,3
1967	270 633	53,1
1968	138 062	37,5
1969	149 195	42,4
1970	169 301	47,2
1971	157 282	48,4
1972	235 642	54,3
1973	250 910	55,6
1974	349 829	87,3
1975	223 612	54,9
1976	218 307	53,6

* No accurate catch records are available for the period between 1943 (when the purse-seine fishery was initiated) and 1949. Large-mesh nets were used and it may be assumed that anchovy catches were negligible. From 1950 to 1957, no anchovy landings were recorded.

apparent that this species was distributed over a wide area off the west coast of South Africa.

Accordingly it was decided to expand the experiment, and permission was granted for a total of 42 small-meshed nets to be used for anchovy fishing during the closed season of that year, three for each of the 14 fishmeal factories then in operation. The balance of these nets had all been delivered from overseas manufacturers by the end of September 1964, at a cost of approximately R10 000 each (Robinson 1966), and subsequent catches were sufficiently good for the authorities to sanction the use of this net by all purse-seine boats (except those licensed for bait catches only) from 1 January 1965. Thereafter the rise in the importance of the anchovy was rapid and, since 1966, it has consistently been the major contributor to the South African purse-seine catch, with a peak of 349 829 tons being recorded in 1974.

In other commercial anchovy fisheries the populations exhibit a reproductive and migratory behaviour that is linked to environmental factors. The northern (Californian) anchovy *Engraulis mordax,* for example, although producing eggs throughout the year, spawns mainly during the boreal winter and spring. In these seasons, prevailin nòrtherly and north-westerly winds off the coas of California give rise to upwelling of cold, nutrien laden water along the shoreward side of the south flowing California Current (Tillman 1972). Adult at this time move off shore to spawn and th ichthyoplankton is subsequently carried toward the mainland by surface currents (Sette 1960). I summer and winter large schools of juvenile an chovy are often found mixing with those of youn sardine *Sardinops caerulea* (Phillips 1952). Th adult stocks meanwhile undertake extensive coast wise migrations (Haugen *et al.* 1969), moving north during late summer with the Davidson countercur rent and south again in winter.

Fishing for the Argentinian anchovy *E. anchoit* is limited to a few months during spring whe large concentrations approach the coast fo spawning. Adults then migrate off shore, and fo the remainder of the year they are intimatel associated with the upwelling of the Falkland Current system. In summer the upwelling zone i at its southernmost position (latitude 39-40°S) but as the year progresses, it moves north along th continental slope, until located off the coast o Uruguay (35—36°S) in winter. The anchovy concentrations follow this shift (F.A.O. 1973).

Off Peru and Chile the distribution of th anchoveta *E. ringens* is practically restricted t the upwelling area of the Humboldt Current system and especially to the region between latitudes 5 and 25°S, within about 80 km of the shore (Boerema and Gulland 1973). Spawning takes place in patches throughout this area, the main season being spring — summer (Einarsson and De Mendiola 1967). Unusual environmental conditions, known as "El Nino", occur at intervals of several years when warm tropical water penetrates south along the Peruvian coast, decreasing or stopping upwelling. This phenomenon upsets the normal distribution pattern of the anchoveta causing it to concentrate in the remaining areas of cool water or to disperse (Boerema and Gulland *op. cit.*).

The Australian anchovy *E. australis* is found along most sections of the coast south of the Tropic of Capricorn, inhabiting estuaries, bays and open waters over the generally narrow continental shelf. The main spawning season is spring through summer and, in some areas at any rate, there appears to be a tendency, increasing with age, for individuals to move from inlets to the open sea in autumn and back again for the spawning period in spring. In autumn the inlets become colder, and in spring warmer, than the open sea (Blackburn 1967).

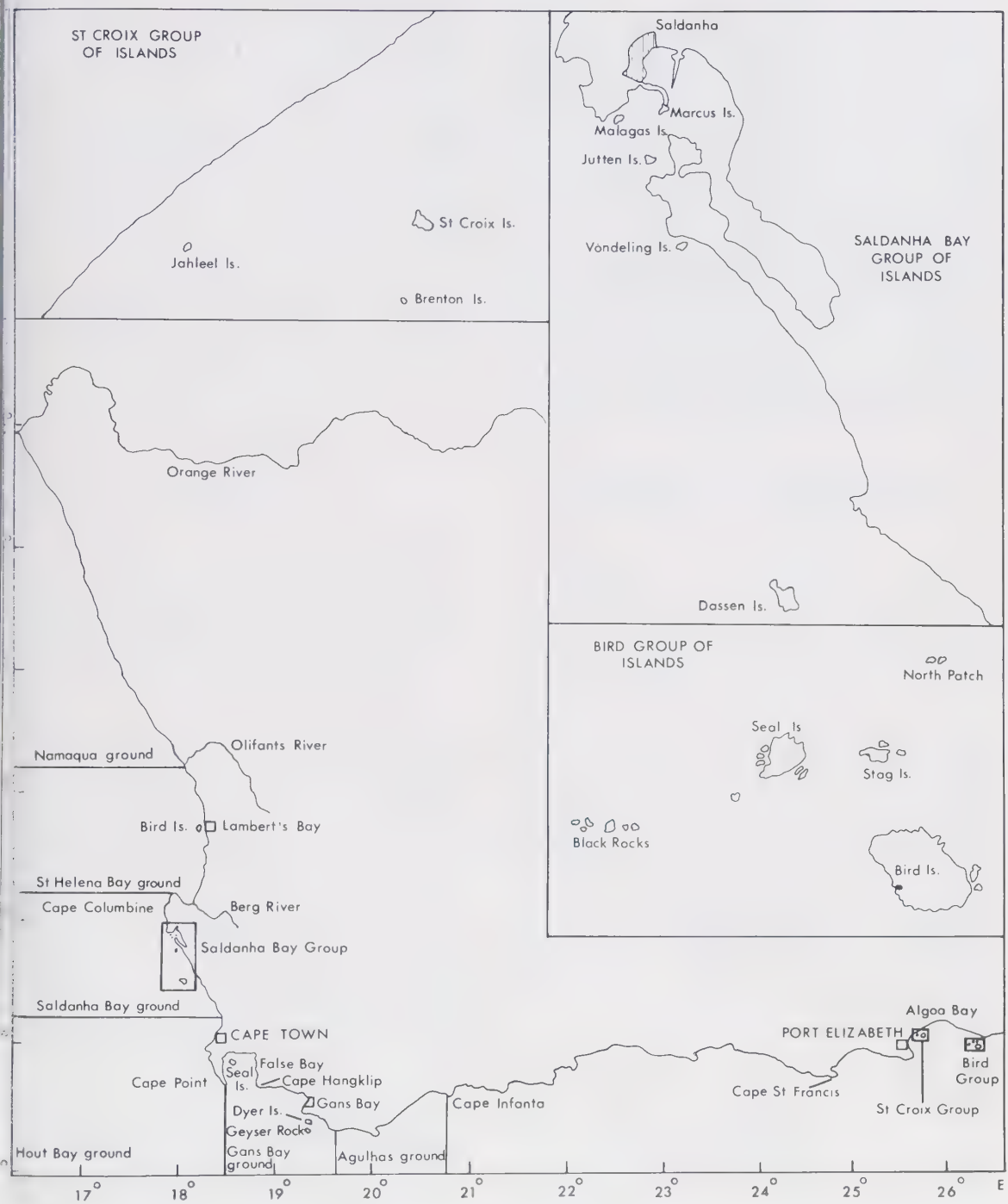


Fig. 1: The main South African purse-seine fishing grounds and the locations of breeding colonies of jackass penguin referred to in the text

Spawning of the Japanese anchovy *E. japonica* takes place off the southern Pacific coast of that country, a region that comes under the influence of the warm Kuroshio Current. The densest concentrations of eggs are encountered during winter or spring. Juveniles occur predominantly in bays and inlets, but adults are also distributed off shore (Hayasi 1967) and further north in the cooler, more productive waters of the Oyashio Current (Nagasaki 1973).

The South African anchovy, too, has definite patterns of distribution and availability, which exert a considerable influence on the deployment of fishing effort over the fishing grounds (Fig. 1). Also, as with the other *Engraulis* species, these patterns can in large measure be related to environmental factors. It is the purpose of this report to both document and quantify these trends and to provide a basis for improving regulatory strategies.

DISTRIBUTION OF COMMERCIAL PURSE-SEINE CATCHES

Monthly distribution patterns of commercial catches of anchovy for the period 1964—1976 were derived in a similar manner to that described for pilchard (Crawford 1981a). The results are presented in chart form in the Appendix, areas in which no fishing was conducted being identified to assist in overall interpretation of the charts and catch rates being given to depict regional differences in the density of fish.

The length compositions of 300 purse-seine catches made between 1974 and 1976 were examined and, as found for the pilchard (Crawford 1981a), it was ascertained that anchovy in South African waters generally shoal by size, individuals from any one haul seldom varying in caudal length by more than 4,0 — 4,5 cm (Fig. 2). Accordingly the modal length of fish caught in known areas, whenever available from samples of catches, has been included on the distribution charts to give some indication of geographical and seasonal differences in the size of anchovy encountered.

Reproductive activity in 1 265 fish sampled during the 1963/64 and 1964/65 spawning seasons (October — January) was investigated by Robinson (1966). His information, when used in conjunction with the growth study of Pollock (1970), suggests that 50 per cent of anchovy attain sexual maturity by the end of their first year and that all mature before they are two years old. For charting purposes, nought-year-old fish were considered to be juveniles

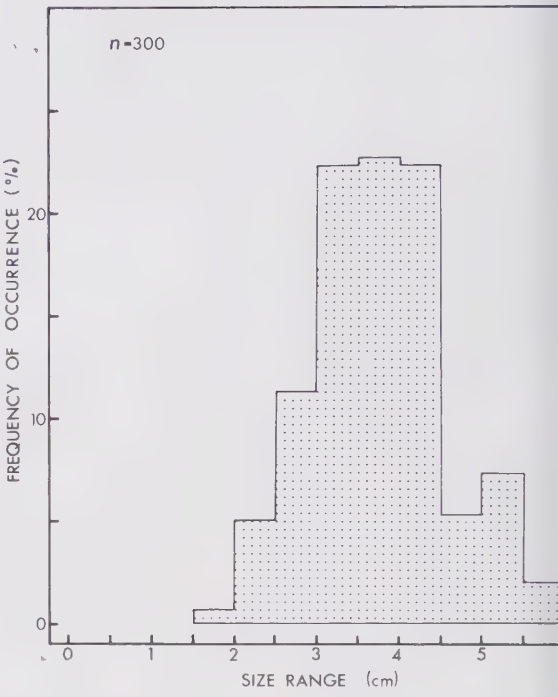


Fig. 2: Frequency of occurrence of size ranges (caud length) of anchovy sampled from individual commercial purse-seine catches

and have been illustrated in different shading fro that used for all older age groups. Thus distributi of recruit year-classes has been highlighted.

The results indicate that, as found for pilcha (Crawford 1981a), almost all catches of ancho are made inside the 200-m bottom contour, exce in the vicinities of Cape Columbine and Ca Point where this isobath approaches the mainlan This pattern could be influenced by the fact th skippers generally choose to stay within sight the coast, especially when fishing alone, becau they rely to a large extent on prominent topogr phical features for navigation. No boats had be equipped with Decca navigation equipment 1976. Notable exceptions to the catch patte were catches of juvenile anchovy made nort west of the Olifants River in June 1966, Janua 1968, April 1971 and August 1976, west of t Olifants River in January 1974, March, May a June 1976, north-west of Cape Columbine April, May and June 1969 and west of Saldanha January 1976; and of adults north-west of t Olifants River in May 1971 and north-west

e Columbine in July 1972. All these records from the northern portion of the fishing grounds. atches of both nought-year-olds and older age ses have been recorded as far north as the nge River (juveniles in June, July and August 5; adults in March 1971) and as far east as e Infanta (juveniles in April 1967, January) and February 1974; adults in June 1964, uary 1966, May 1973, April 1974 and June 5). It has seldom been necessary for boats to el such distances, however, and fishing in these as has not been intensive (Crawford 1981b). ther east anchovy have been recorded in the machs of hake *Merluccius* sp. trawled off Port abeth (Hecht 1976), and larvae have been found Cape St Francis (Shelton and Kriel 1980). dence of spawning off East London and Natal been documented by Anders (1975).

AVAILABILITY, ABUNDANCE AND MOVEMENTS

easonal patterns of availability and distribution wo age categories (nought-year-olds and all r fish) were quantified by dividing the fishing into six grounds (Fig. 1), selected to correspond the major environmental regions of the South-tern Cape (Crawford *et al.* 1980). As illustrated e Appendix, the seaward extension of these nds is seldom greater than 50 km and they herefore of approximately equal size, except he extensive but relatively lightly exploited aqua area.

onthly indices of availability and of the relative dance of fish that could, as a rule, be expected e present on each of the six grounds were rmined by a method analogous to that described he pilchard population (Crawford 1981a) for h nought-year-old anchovy and the older age ps. Only the years 1965—1976 were considered, use fishing with the small-meshed net in 1964 restricted to between 6 and 42 boats only. ues were not calculated for October, November December because, after 1965, the season was sed during these months.

he resulting estimates, expressed as percentages he maxima, appear in Figures 3 and 4. The ds exhibited by the fully recruited age classes probably determined to some extent by rtality, especially that caused by fishing, with ch rates declining as the season progresses. wever, an unrealistically high value of total rtality ($Z = 3{,}9$) would be required to produce

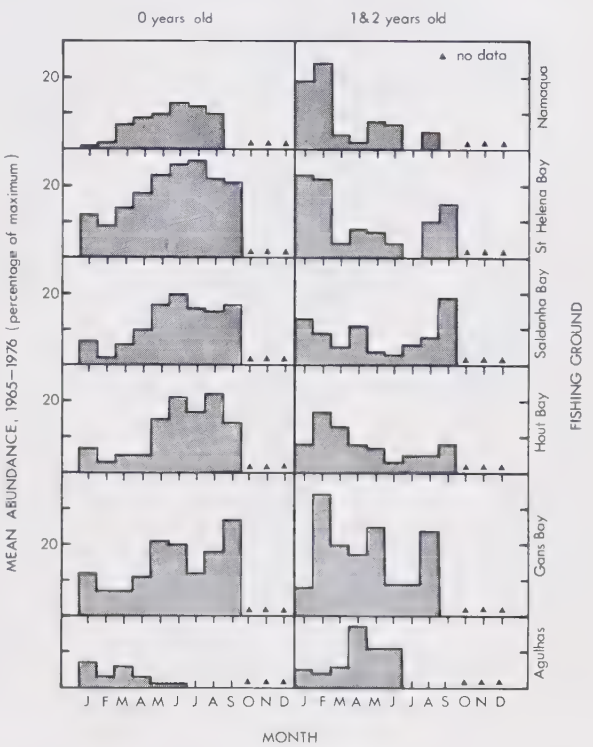


Fig. 3: Age-specific monthly abundance indices for anchovy for six fishing grounds

the observed decline in availability. A natural mortality value of 0,8 was calculated for this population from the age composition of the relatively unfished 1965 stock, whereas estimates of fishing mortality for the period 1965—1976 have ranged between 0,57 and 1,09 with a mean of 0,70 (Centurier-Harris *et al.* 1977). Undoubtedly, therefore, fish movements also exert a considerable influence, as is evident from a bimodality in abundance indices for the St Helena Bay, Saldanha Bay, Hout Bay and Gans Bay grounds. These will be discussed in greater detail when considering the adult population.

Spawning

Both migrations (Jones 1965) and patterns of recruitment may be considerably influenced by spawning behaviour. Information on the surface distribution of anchovy eggs between Lambert's Bay and St Sebastian Bay is available for the period 1964—1969 (A.S. Anders, Sea Fisheries

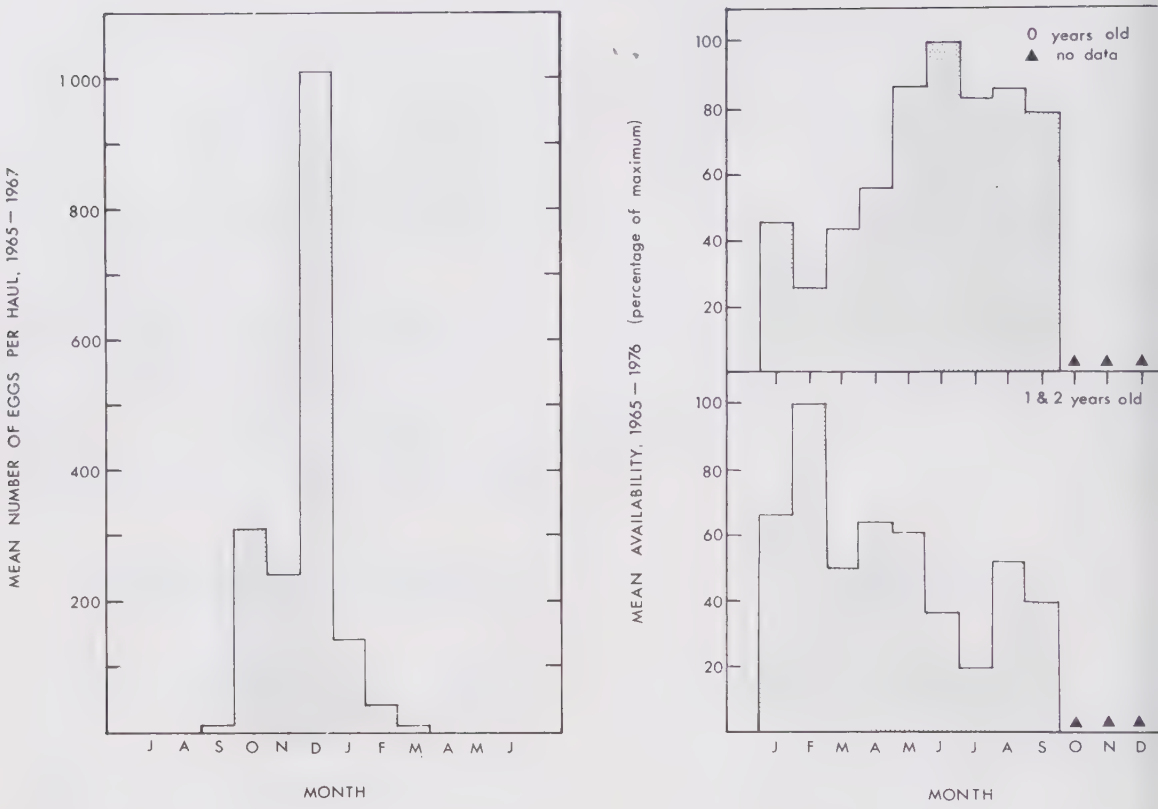


Fig. 4: Monthly egg production and availability indices for anchovy off South Africa

Institute, unpublished manuscript). The data are not strictly quantitative, the survey having been conducted with the surface-sampling N 100 H net whereas the vertical distribution of eggs of this species extends to the thermocline (Shelton and Hutchings 1979). However, spawning was largely confined to the period October — January (Fig. 4), when the 1964--1969 surveys were made. Eggs were generally present in their densest concentrations in the waters east of Cape Point (Fig. 5a-c).

Nought-year-old fish

Juvenile anchovy recruit to the fishery in steadily increasing numbers after February with availability reaching its highest level in June (Fig. 4), six months after the peak in egg production. This time lag is similar to those in the fisheries for Peruvian anchoveta (Schaefer 1967) and northern (Cali nian) anchovy (Tillman 1972). From June u September the young anchovy are generally cau in large quantities. The pattern therefore clos resembles the one exhibited by pilchard (Crawf 1981a), a fact probably accounted for beca the two species frequently shoal together dur their early stages. Furthermore, like pilchard, anchovy recruits move south, catches on the t northern grounds declining after June or July a fishing for this age group being most reward east of Cape Point in September (Fig. 3).

Although indices were not calculated for Octo — December, fairly good catch rates were recor during these months in 1964 (Appendix). Availab at this time probably decreases to the moder level estimated for January when, on avera over 40 per cent of the age group is located eas Cape Point and more than 70 per cent soutl

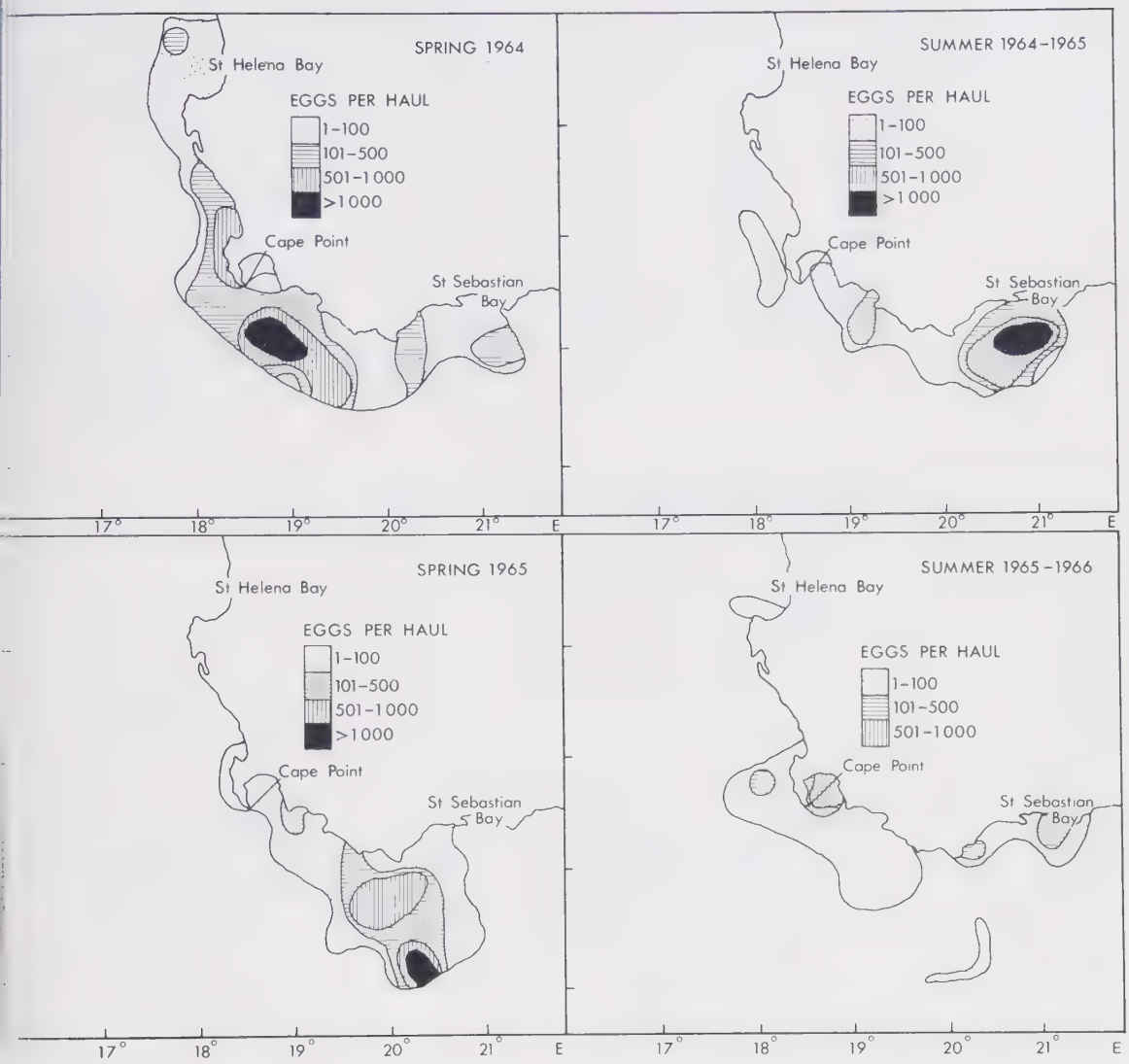


Fig. 5a: Surface distribution of anchovy eggs off South Africa, 1964—1966 (modified from A. S. Anders, Sea Fisheries Institute, unpublished manuscript)

ape Columbine.

The pattern of recruitment is highly regular e Appendix), being clearly evident in every ason with the possible exception of 1974, which as closed from 26 June as a result of the quota ing filled considerably earlier than usual (Crawrd 1981b). Catch rates greater than 50 metric ns per standard-boat-day were frequently recorded from May onwards, but were uncommon during the first four months of any season (Table II). The good catches of juvenile anchovy during summer and early autumn of 1974 and 1975 can probably be attributed to the premature closure of the previous (1973 and 1974) seasons, in both of which no catches of anchovy were permitted after the end of June. Therefore, exploitation of nought-

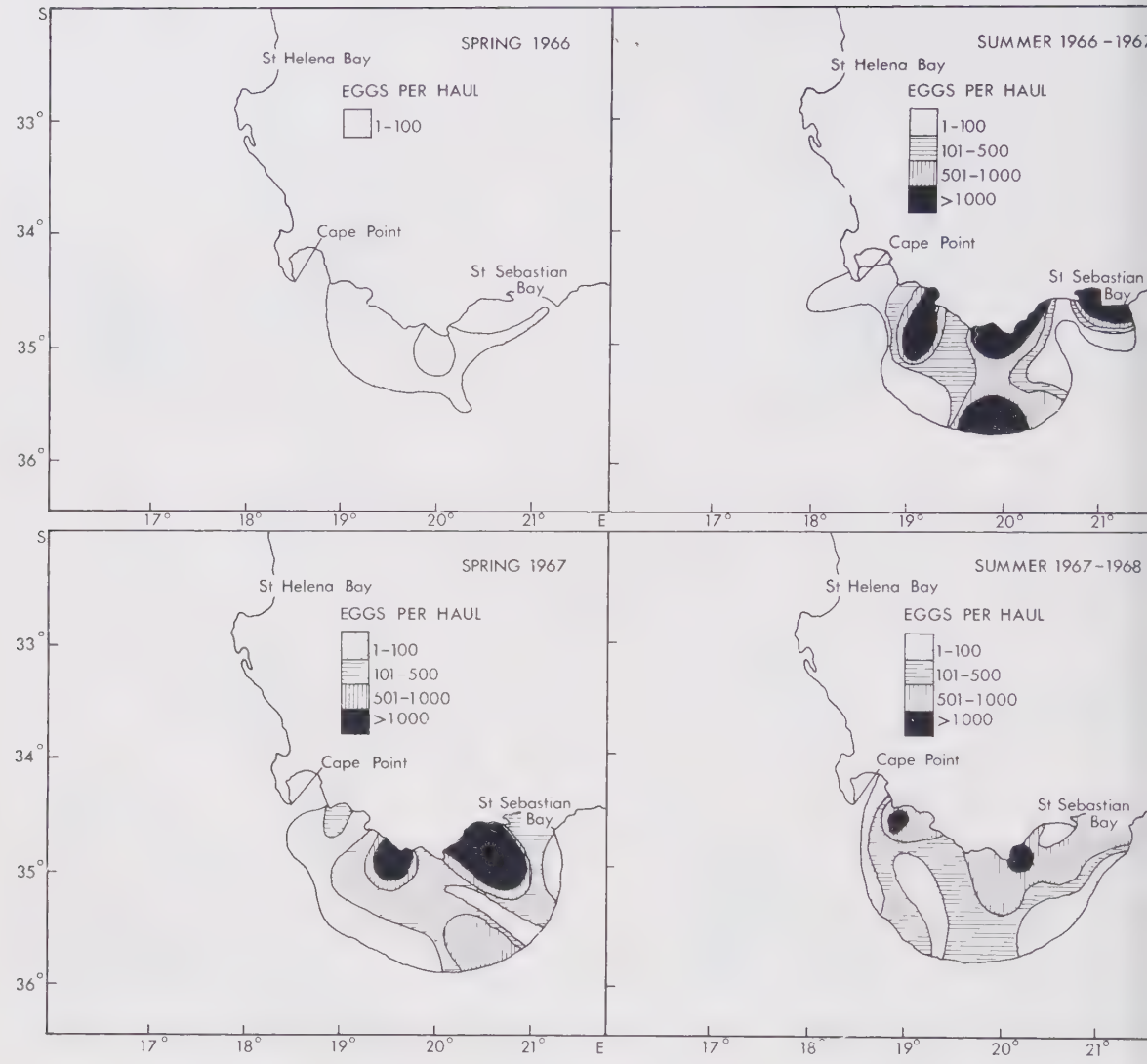
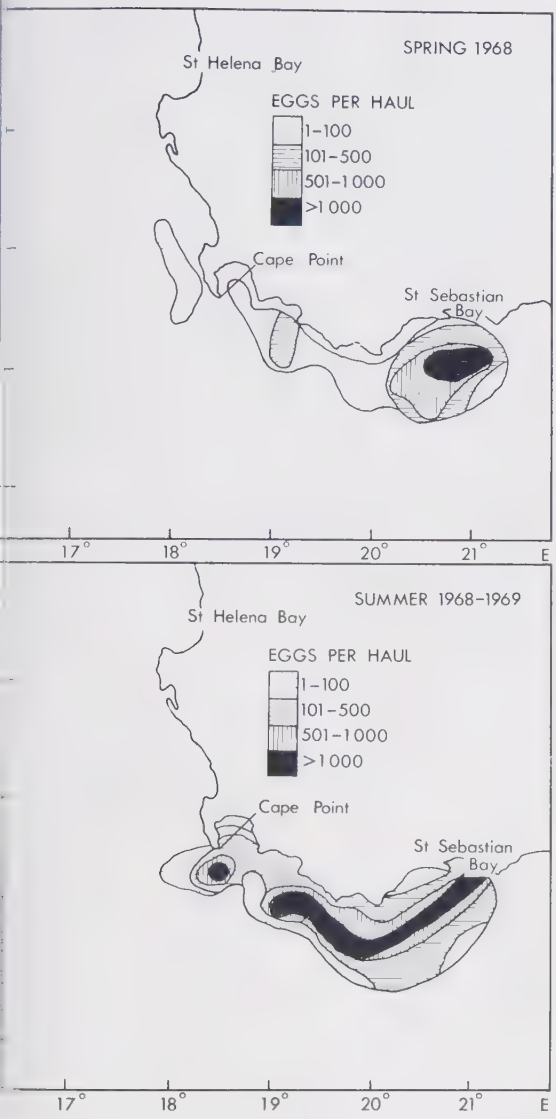


Fig. 5b: Surface distribution of anchovy eggs, 1966–1968 (modified from A. S. Anders, Sea Fisheries Institu unpublished manuscript)

year-old fish in these two years was curtailed, and better than normal catches in the following two years resulted.

Southward movement is apparent from the increased tendency to fish south of Cape Columbine during winter or at the onset of spring (August/September 1964, July/August 1965, August/September 1966, August/September 1967, July–Septemb 1968, August 1969, August 1970, July/August 197 July 1972, June 1973, August 1975, July 197 although good catches in the northern areas a still made at this time. Also, the size of nougl year-old anchovy tends to increase in the southe and eastern fishing areas, indicating that individu



5c: Surface distribution of anchovy eggs, 1968–1969 modified from A. S. Anders, Sea Fisheries Institute, unpublished manuscript)

these waters are somewhat older than those rther north. The modal caudal length of fish ught on the Namaqua and St Helena Bay grounds as less than 8,0 cm for 26 of the possible ground-onth combinations, compared with 13 instances r the Saldanha Bay and Hout Bay regions and ly 4 east of Cape Point.

Table II: Months in which catch rates of nought-year-old anchovy greater than 50 metric tons per standard-boat-day have been recorded

Month	Season
January	1974, 1975
February	1974
March	1971, 1974
April	1969, 1975
May	1966, 1967, 1973, 1974, 1976
June	1965, 1966, 1967, 1968, 1969, 1973, 1975, 1976
July	1965, 1966, 1967, 1975, 1976
August	1964, 1965, 1967, 1975, 1976
September	1964, 1965, 1966, 1968
October	1964
November	1964
December	—

One-and two-year-old fish

Preliminary analysis revealed that the adult anchovy age classes behaved in a similar fashion and they are therefore considered together. The adult age classes are predominantly one- and two-year-olds (Fig. 6), because the high mortality rate results in very few older individuals surviving. They are most available in summer, and catch rates decline as winter approaches (Fig. 4). This may be partly attributable to fishing pressure, but fish movements probably also exert an important influence. At the start of the year the adults are distributed throughout most of the fishing region, but thereafter they frequently undertake a migration to the south and east (Fig. 3). This migration is similar to that of pilchard aged between two and four years (Crawford 1981a), although the pilchard are usually slightly further east. In autumn and winter adult anchovy are most abundant on the grounds east of Cape Point, then at the beginning of spring they show a tendency to return to the western areas, being caught between St Helena Bay and Hout Bay. Spring and summer spawning sometimes takes place in this region, but it mainly occurs in the waters east of Cape Point (Fig. 5 a-c).

The south-east displacement during the austral winter is evident from the distribution of the commercial catches in 1964, 1965, 1966, 1968, 1969, 1970, 1973 and 1975 (Appendix). Good hauls of adult anchovy may also be made off the West Coast at this time of the year, as was the case in 1964, 1965, 1971 and 1974. During 1964 and 1965, however, these catches could have resulted from

the fact that the virgin stock had not yet been substantially reduced, because rewarding fishing was also recorded further south in those years. The summers of 1971 and 1974 provide the only known instances of adult anchovy being caught north of 30°S and, even in these years, there was a slight movement to the south in winter.

DISCUSSION

Comparison of the behaviour of the anchovy population with that of the pilchard (Crawford 1981a) reveals close similarities which can be related to the environmental features of the region (Crawford 1980, Crawford *et al.* 1980). Most catches of both species are recorded inside the 200-m bottom contour and, in the few instances that successful hauls have been made further off shore, they have almost invariably been from the northern regions and have generally been of juveniles. It is possible that these fish may, as larvae, have been carried away from the West Coast by surface currents, which during summer frequently flow in a northerly to north-westerly direction (Shannon 1966).

Since 1966, spawning by both anchovy and pilchard has been heaviest east of Cape Point where relatively warm temperatures promote the rapid development of eggs and larvae. Subsequent dispersal of the ichthyoplankton is into the Benguela Current system. Here spring and summer upwelling ensures an abundant food supply for the early stages. Shelton and Hutchings (1979) have demonstrated the importance of the Good Hope jet (Bang and Andrews 1974) in the transportation of eggs and larvae towards the northern nursery areas. It is on these grounds that juveniles of both species, frequently shoaling together, recruit to the fishery in their highest numbers in late autumn or early winter. At the advent of spring they move south for the next spawning season, possibly taking advantage of inshore countercurrents (Duncan and Nell 1969). After spawning, anchovy and the younger pilchard adults frequently migrate off the fishing grounds in an easterly direction.

Certain differences in the behaviour of the two species are also apparent and can be attributed mainly to the younger age at maturity of the anchovy and the longer lifespan of the pilchard. Substantial numbers of juvenile pilchard, for example, remain on the West Coast until well into their second year of life when they first start to become reproductively active (Crawford 1981a). At younger ages, pilchard have no need to mo for spawning purposes to the warmer water furth south, but instead are able to stay in the high productive upwelling regions west of Cape Poin Furthermore, large quantities of five- and six-yea old pilchard contributed to the commercial landin prior to the introduction of the 12,7-mm net, bei especially abundant in the northern fishing area Here they consistently gave rise to dense conce trations of eggs during spring and summer (Crawfo *et al.* 1980). By contrast, a high natural mortali rate means that anchovy seldom attain this ag (Fig. 6). Anchovy spawning is generally limited the southern grounds (Fig. 5), which may be becau eggs and larvae of the species are less tolerant cold water than are those of pilchard, having lower lethal limit of 14°C as opposed to the 13° for pilchard (King *et al.* 1978). Between 1964 an 1967, when measurements were stopped, surfac temperatures in the northern pilchard spawnin region never dropped below 13°C during sprin and summer. However, values of 14°C, or slight lower, were recorded (Sea Fisheries Institut unpublished data).

Although the spring and autumn migrations anchovy always appear to be in the same directio the adult age groups have a less consistent distrib tion than those of pilchard. In winter adult ancho may occur in dense concentrations on the norther fishing grounds or alternatively be situated east Cape Point.

Flightlessness limits the feeding range of th jackass penguin *Spheniscus demersus,* leading Fro *et al.* (1976) to suggest that this bird must be ab to rely on a highly predictable temporal and spati distribution pattern of its prey. As the pilcha satisfies this requirement to a greater degree tha does the anchovy, the decline of the pilcha resource during the sixties could have been expecte to be followed by a decrease in the pengu population (Crawford and Shelton, in press), spite of the availability at that time of a lar anchovy stock. Recent census figures support th idea (Table III). Since 1956, there has been substantial decrease in the numbers of penguin at all colonies located west of Cape Hangklip (s Fig. 1). By contrast, the colonies further east ha retained a relatively stable population or, in th case of Dyer Island, have shown a large increa in numbers of penguins.

These eastern colonies fall within the distrib tional range of pilchard aged 2—4 years, whic still contribute substantial purse-seine catche

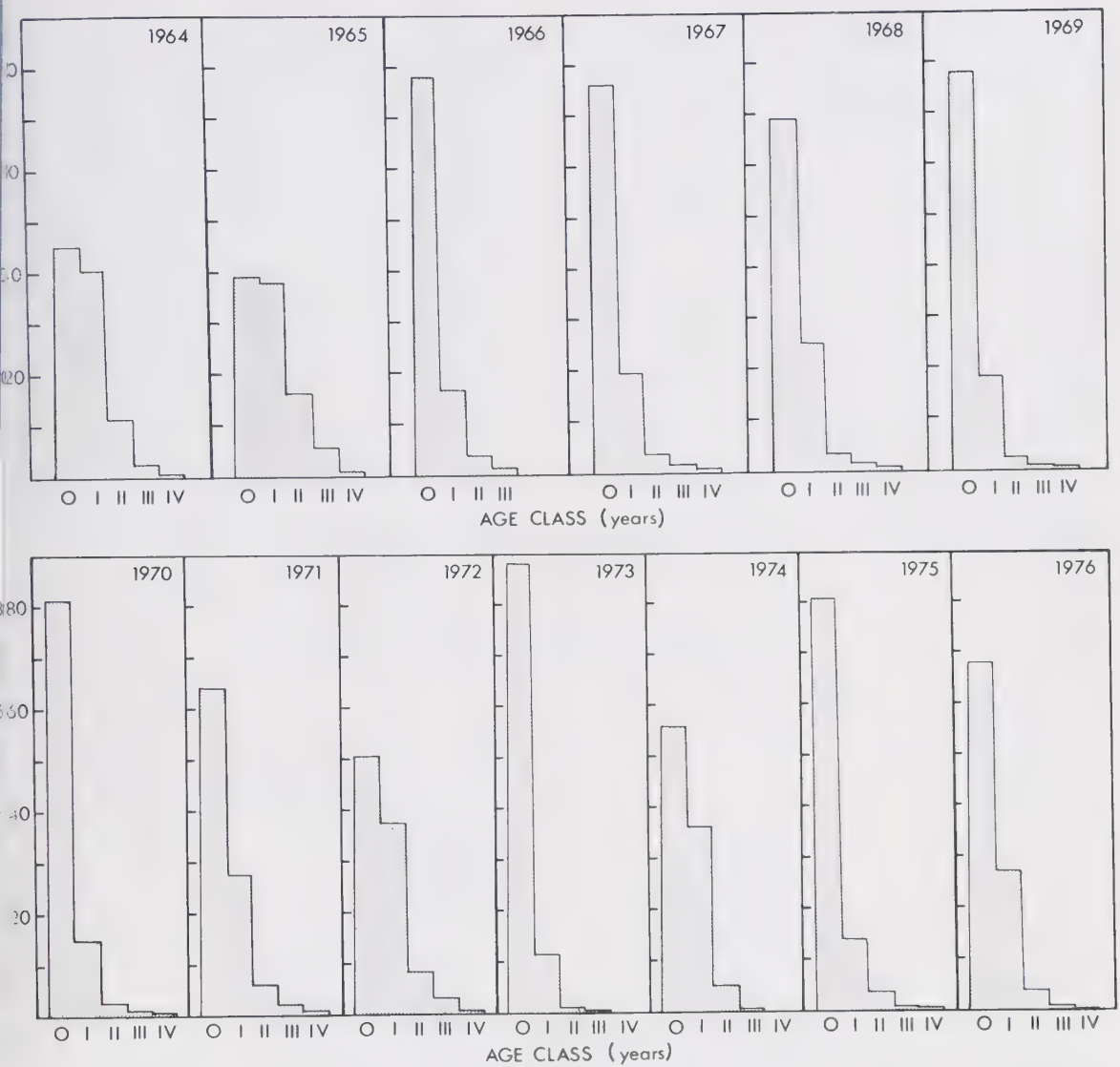


Fig. 6: Age composition of South African anchovy landings, 1964—1976 (data after Crawford *et al.* [1978])

Whereas the western colonies would have been largely dependent on the older pilchard age classes, which have been virtually eliminated (Crawford 1981a).

Anchovy spawning and the pattern of nought-year-old recruitment are highly predictable and greatly facilitate control of the fishery. Therefore, amid other considerations, the current closed fishing season in South Africa (September—December inclusive) has been selected to include those three months in which the highest anchovy egg yields have been recorded (Fig. 4). Additional control possibilities also exist, for example differential exploitation of particular age classes or increasing the age at first capture by regulating deployment of fishing effort.

Table III: Population estimates for jackass penguin colonies located off South Africa, 1956 and 1978-1979

Colony	Estimated number of adults breeding during spring and summer		Change between 1956 and 1978-1979	
	1956*	1978-1979**	Actual	Per cent
Bird Is. (Lambert's Bay)	500	20	−480	−96,0
Malagas Is.	5 000	1 152	−3 848	−77,0
Marcus Is.	9 500	748	−8 752	−92,1
Jutten Is.	15 000	4 794	−10 206	−68,0
Vondeling Is.	600	552	−48	−8,0
Dassen Is.	145 000	22 440	−122 560	−84,5
Seal Is. (False Bay)	500	100	−400	−80,0
Dyer Is.	8 000	37 424	+29 424	+367,8
Geyser Is.	No data	302		
Jahleel Is.	No data	300‡		
Brenton Is.	No data	21‡		
St Croix Is.	12 000	11 591‡†	−409	−3,4
Seal Is. (Algoa (Bay)	300§	2 213‡	+1 913	+637,7
Stag Is.	42	120‡	+78	+185,7
Bird Is. (Algoa Bay)	500	1 098‡	+598	+119,6

* From Rand (1963) — estimated from aerial photography, combined with ground observations
** From Crawford *et al.* (in preparation) — estimated from nest counts unless otherwise indicated
§ 1958 census
‡ Estimated from head count
† R.M. Randall, University of Port Elizabeth, personal communication (count for November 1979)

ACKNOWLEDGEMENTS

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This report is based on a section of a dissertation submitted in September 1979 as part requirement for the degree of Doctor of Philosophy at the University of Cape Town.

APPENDIX

ANCHOVY CATCH LOCATIONS 1964—1976

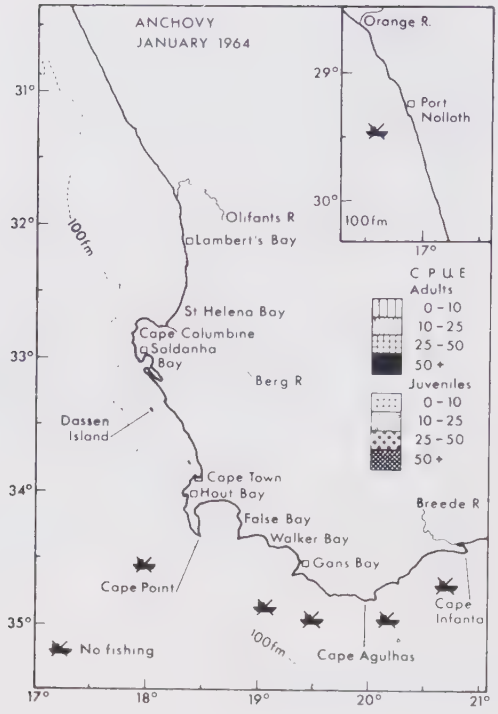
From 1969 to 1976 no charts are shown for September — December inclusive, because exploitation of anchovy was prohibited during these months.

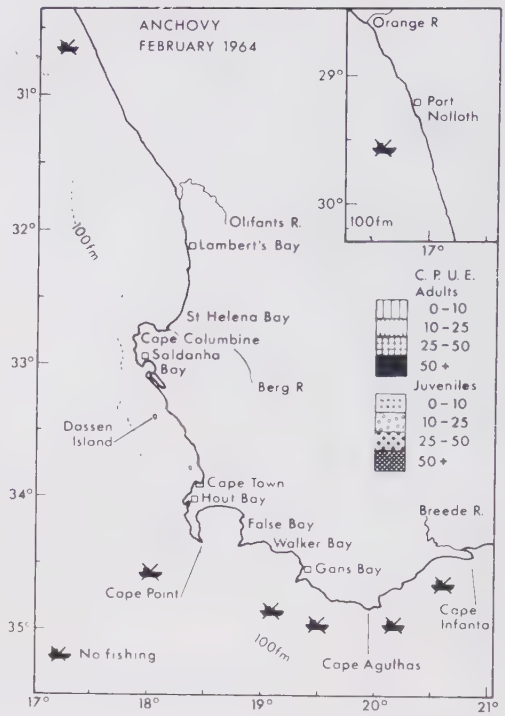
Levels of catch per unit effort (C.P.U.E.) are indicated as metric tons per standard-boat-day.

Modal caudal lengths (cm) of fish from different areas are shown adjacent to catch locations. Growth rates may be expected to vary between seasons, but some indication of age is provided by the von Bertalanffy growth equation (Pollock 1970):

Age (years)	Predicted caudal length (cm)
1	7.9
2	11.1
3	12.6
4	14.2
L_∞	14.8

Areas in which there was no deployment of fishing effort are shown.


ANCHOVY
JANUARY 1964
Orange R.
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +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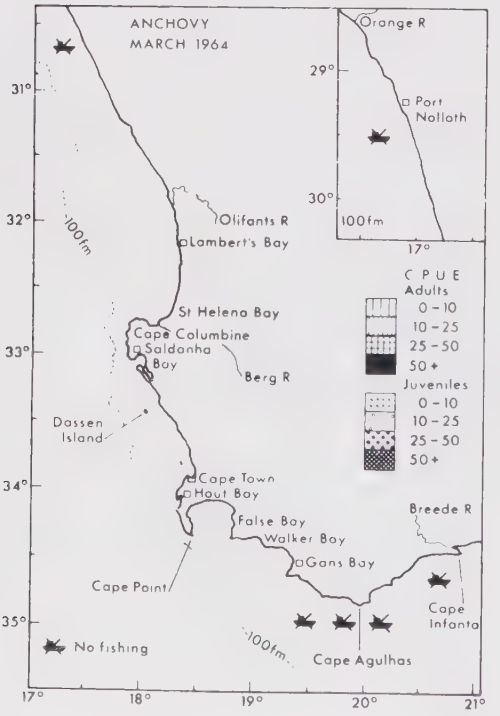
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C. P. U. E.
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +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St Helena Bay
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Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 – 10
10 – 25
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Juveniles
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10 – 25
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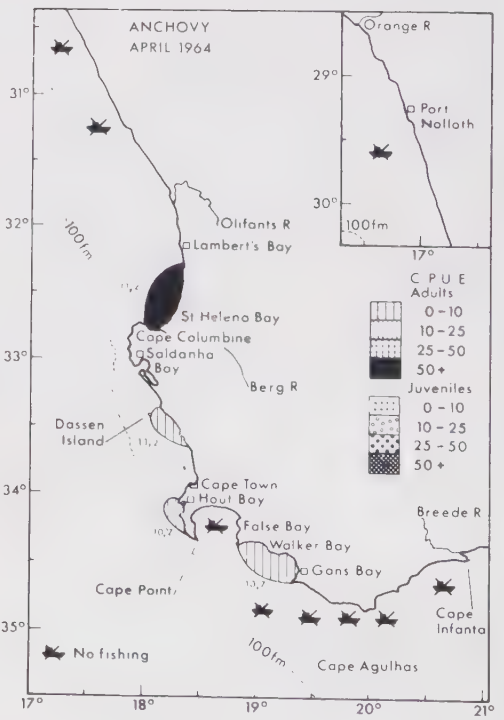
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Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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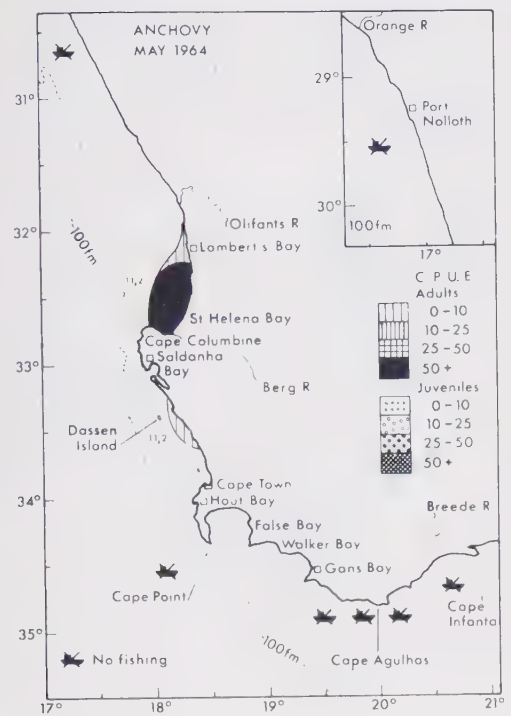
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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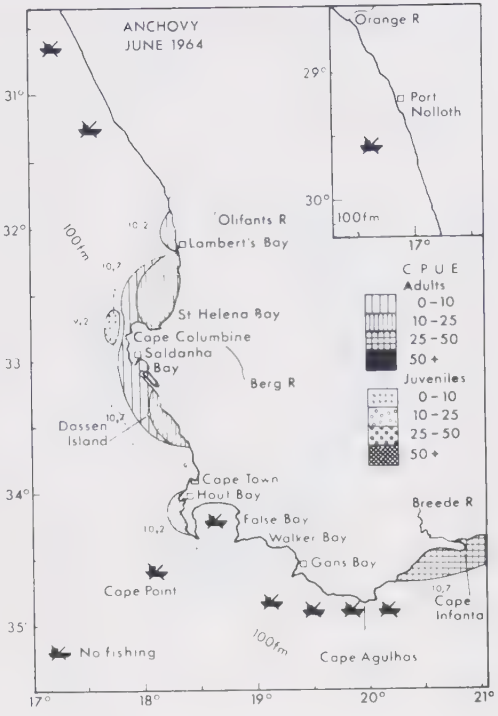
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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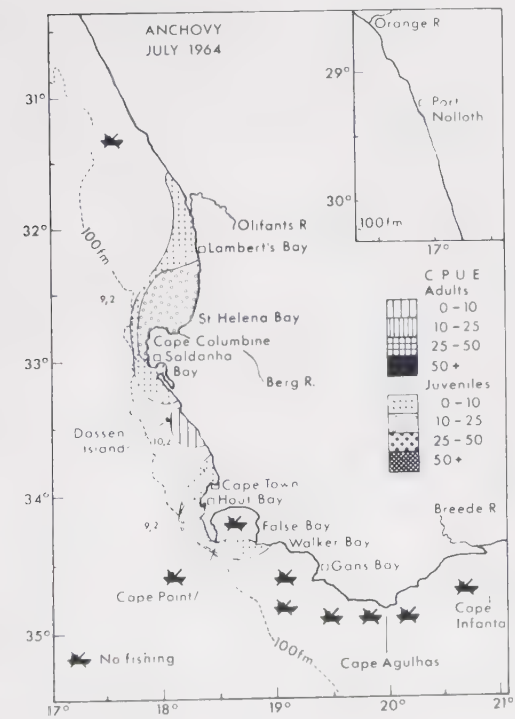
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Port Nolloth
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Cape Point
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No fishing
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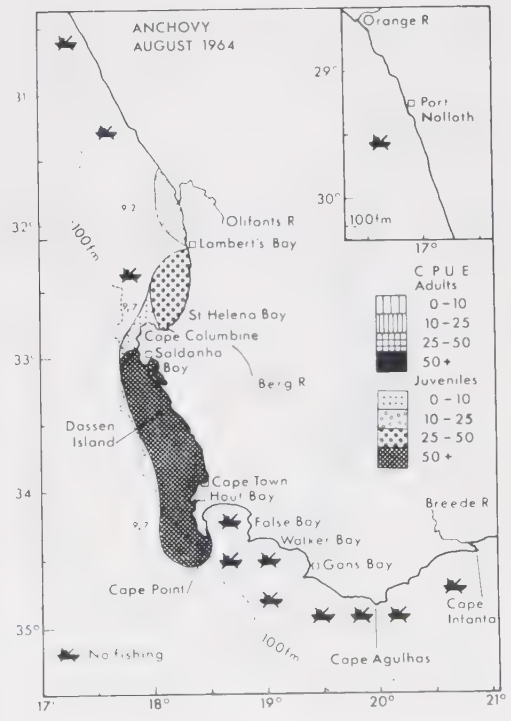
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Olifants R
Lambert's Bay
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Saldanha Bay
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Cape Agulhas
No fishing
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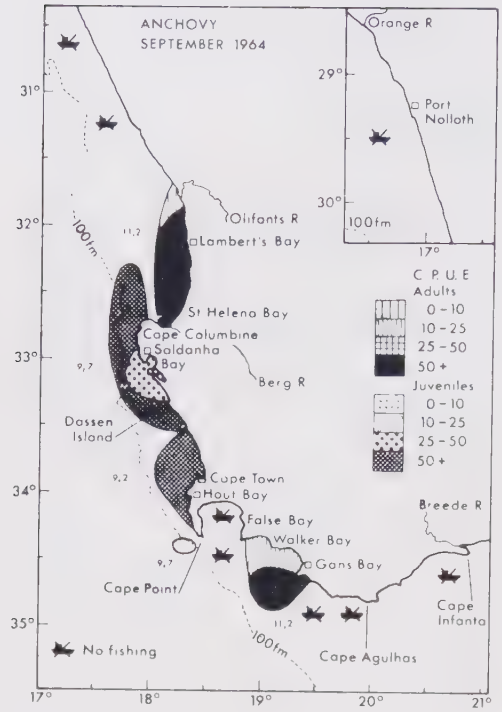
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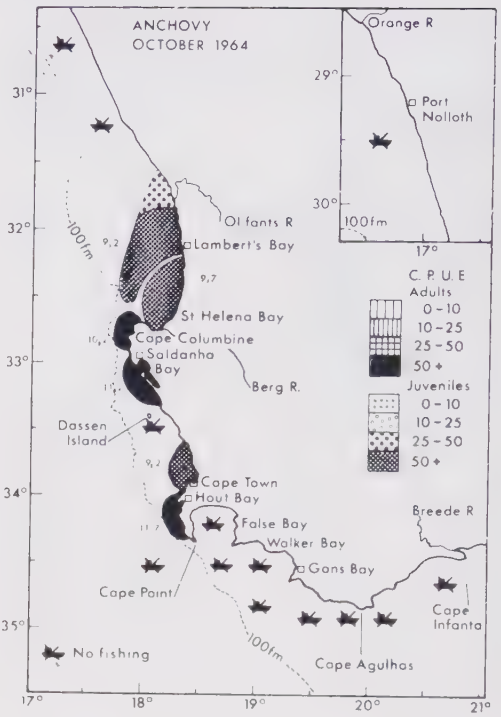
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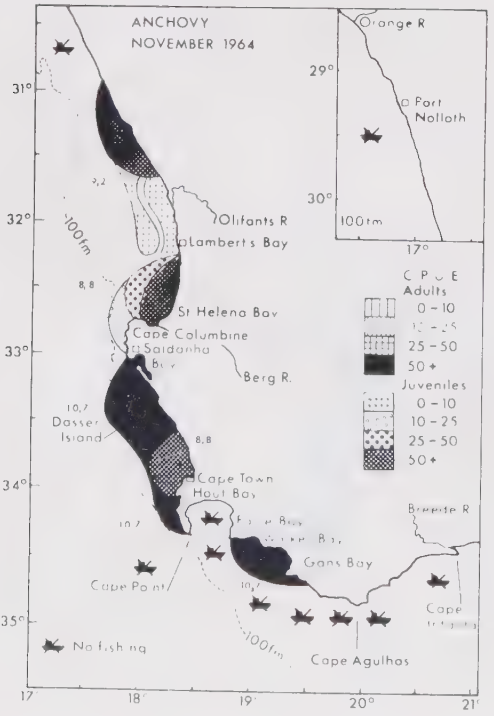
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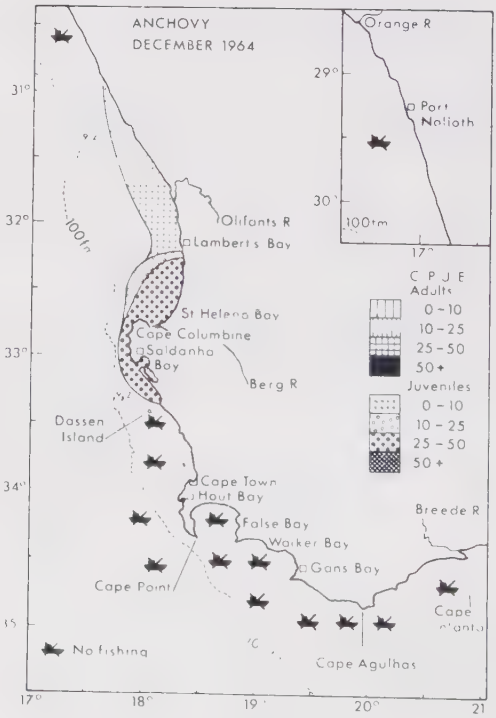
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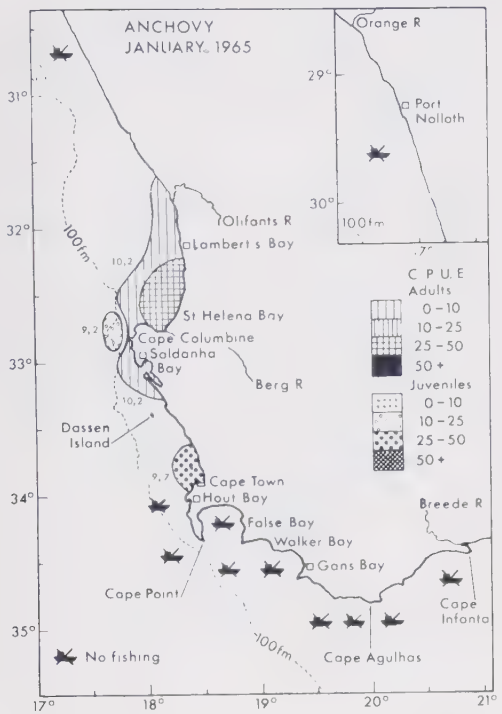
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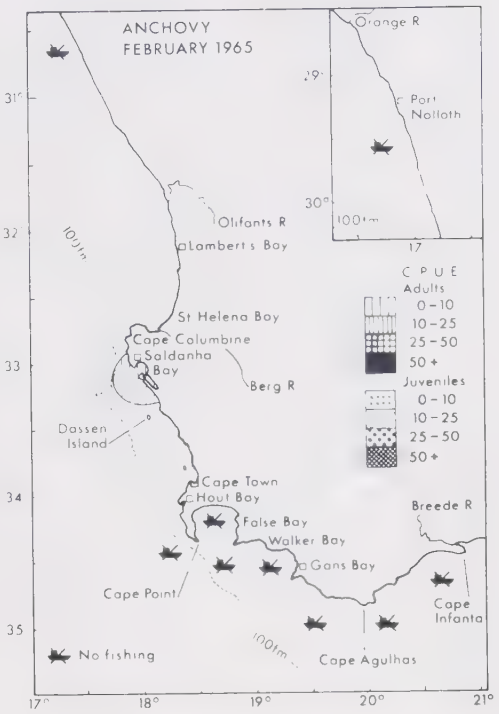
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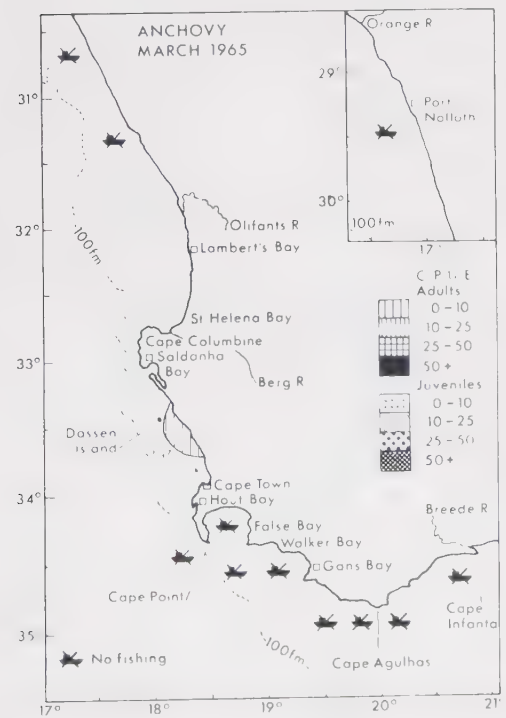
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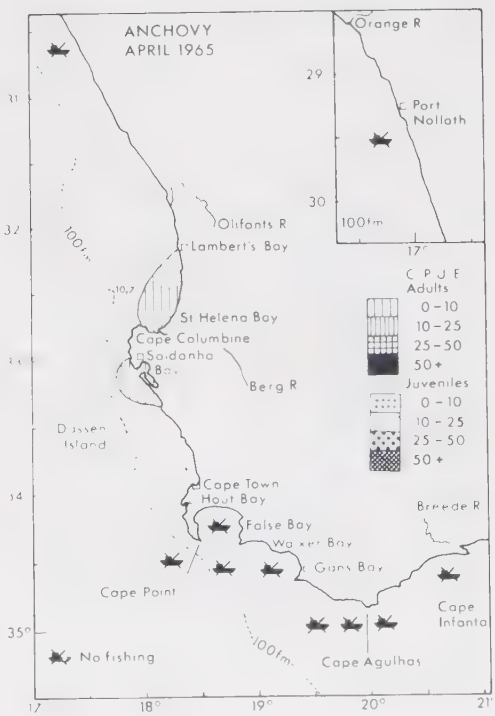
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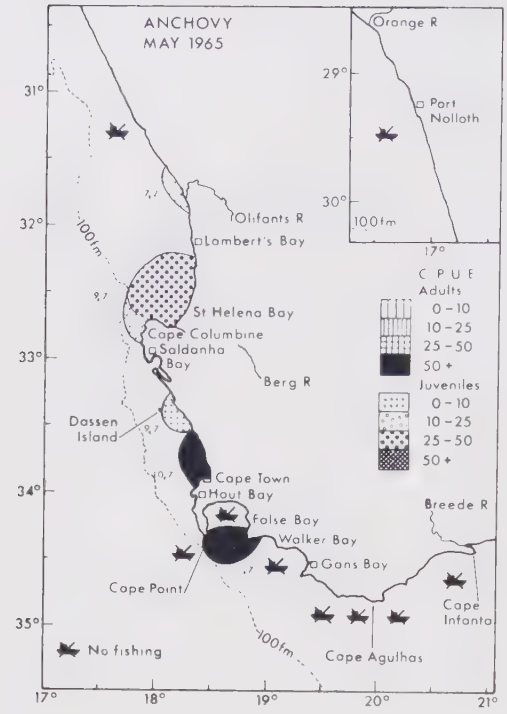
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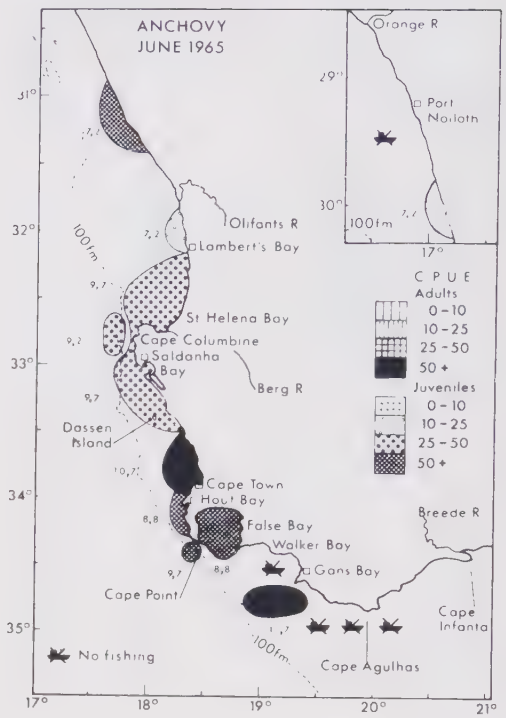
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JUNE 1965
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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Juveniles
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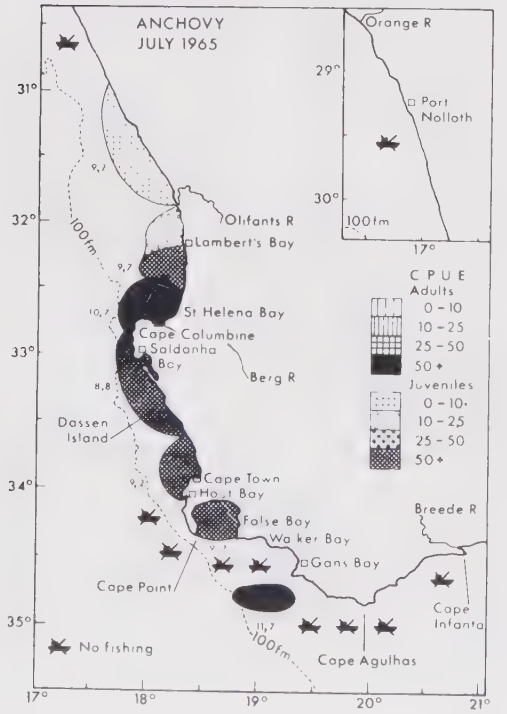
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JULY 1965
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Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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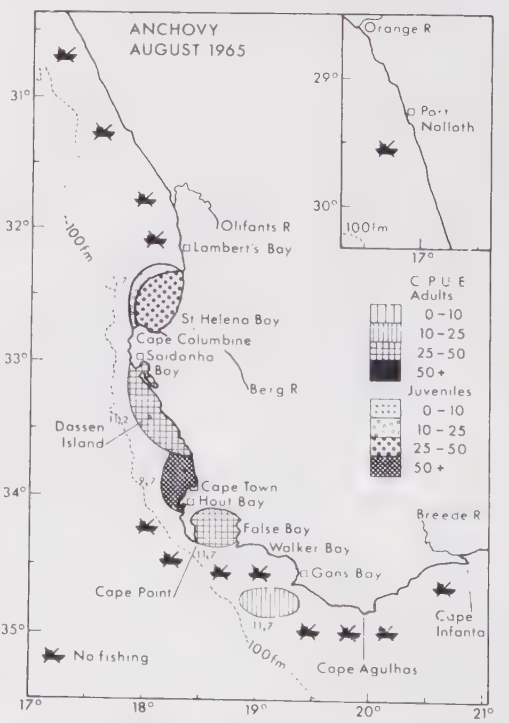
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AUGUST 1965
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Cape Town
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False Bay
Walker Bay
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Breede R
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Juveniles
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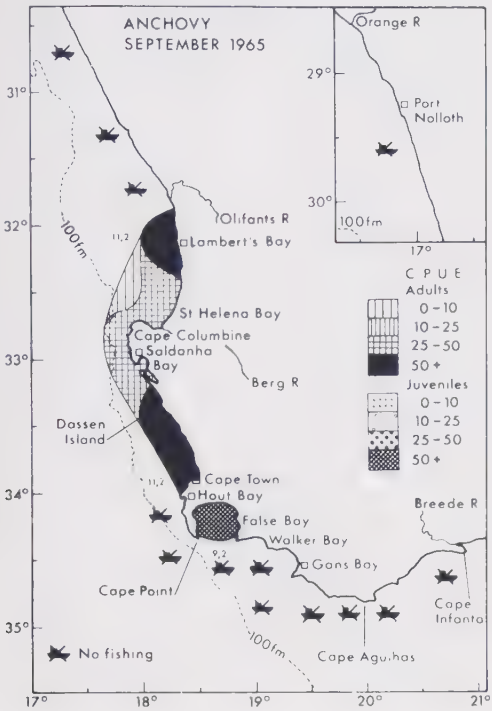
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Dassen Island
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Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
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Juveniles
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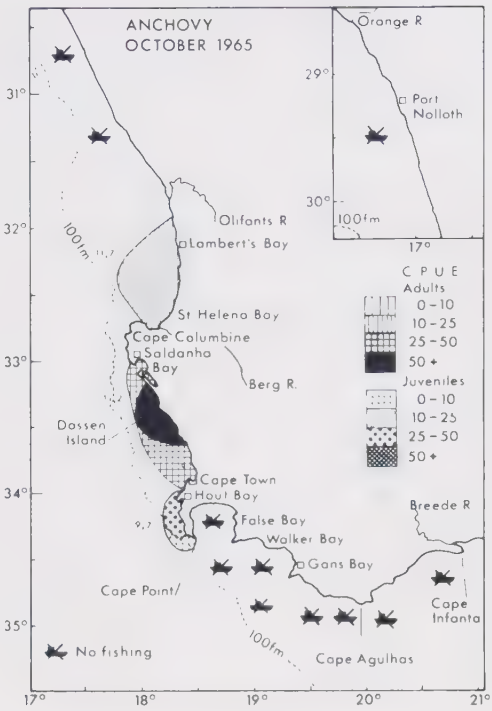
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OCTOBER 1965
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Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point/
Cape Infanta
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Juveniles
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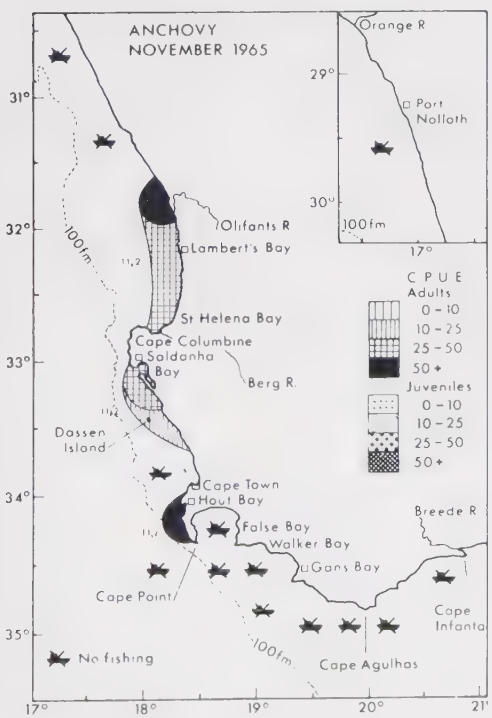
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Dassen Island
Cape Town
Hout Bay
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Juveniles
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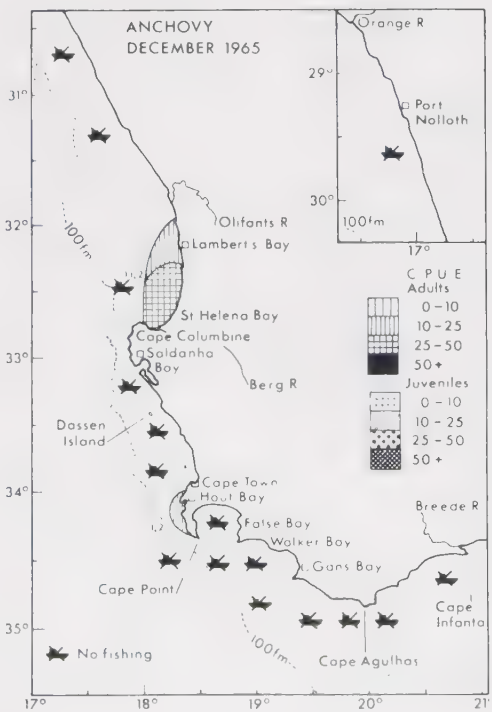
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DECEMBER 1965
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Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
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Cape Infanta
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Juveniles
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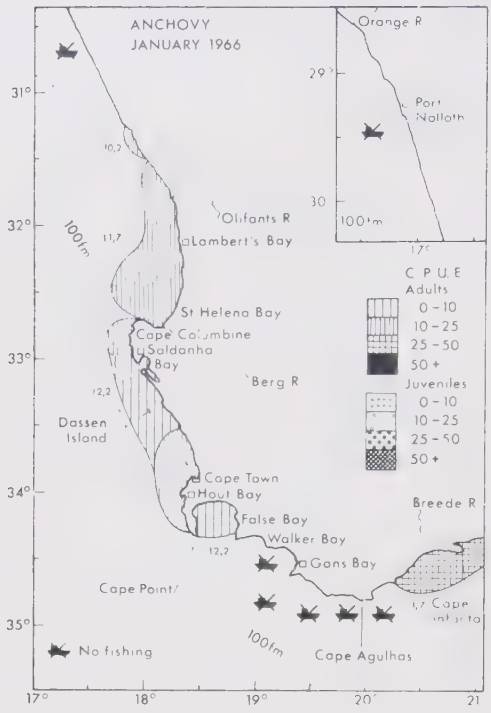
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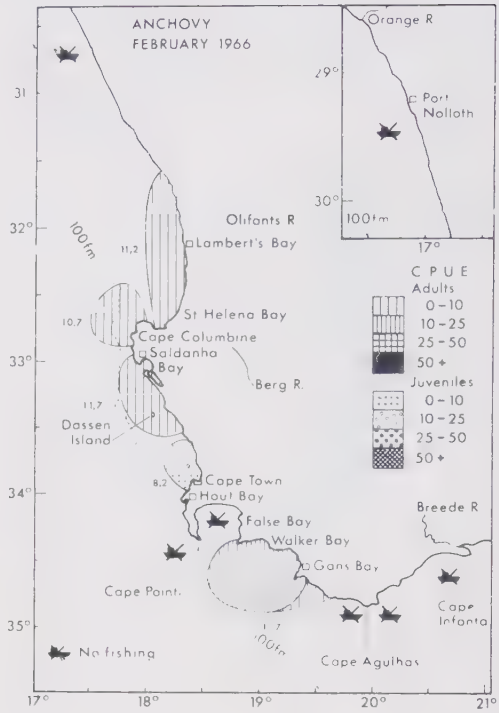
ANCHOVY
FEBRUARY 1966
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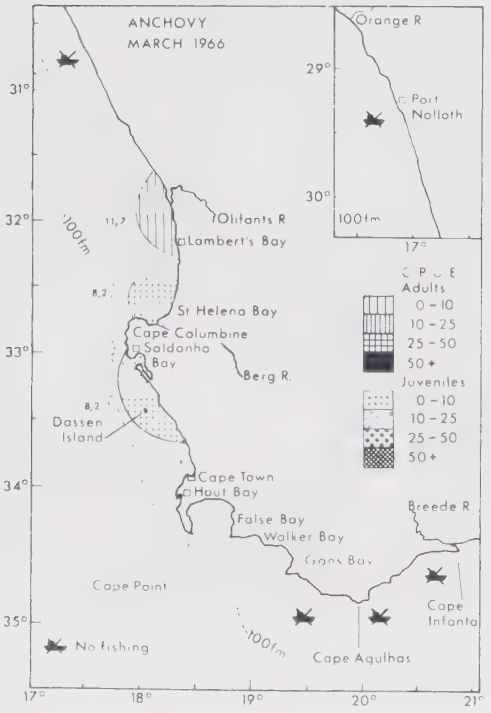
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MARCH 1966
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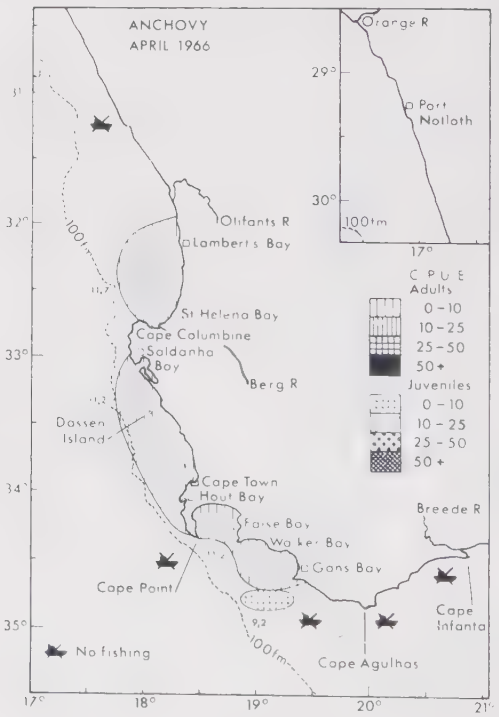
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APRIL 1966
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Lambert's Bay
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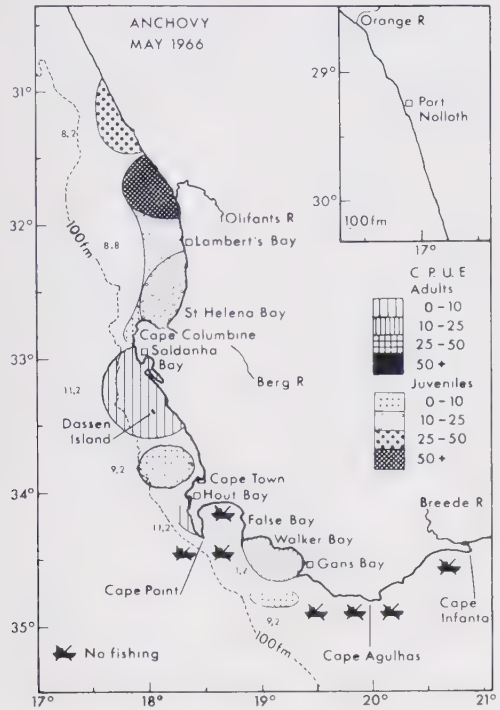
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MAY 1966
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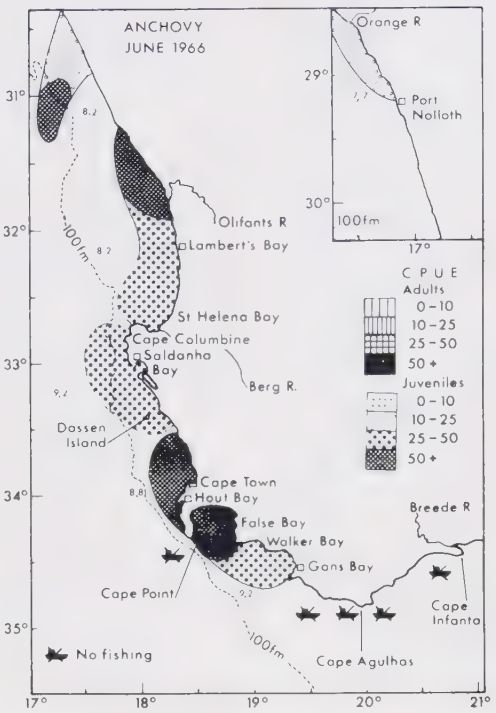
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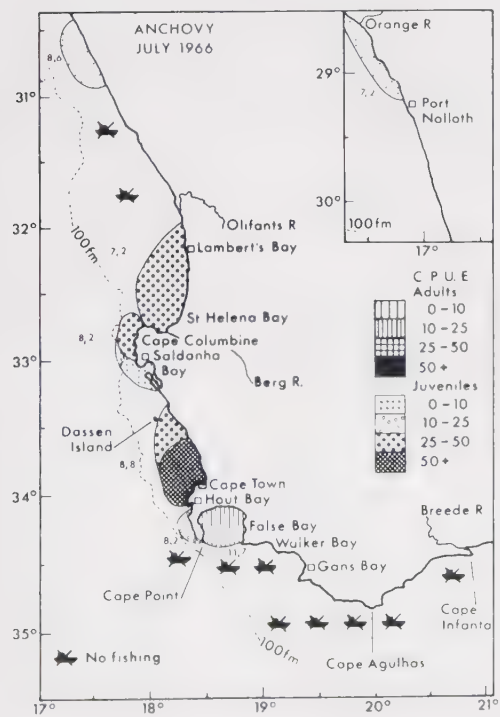
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JULY 1966
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Juveniles
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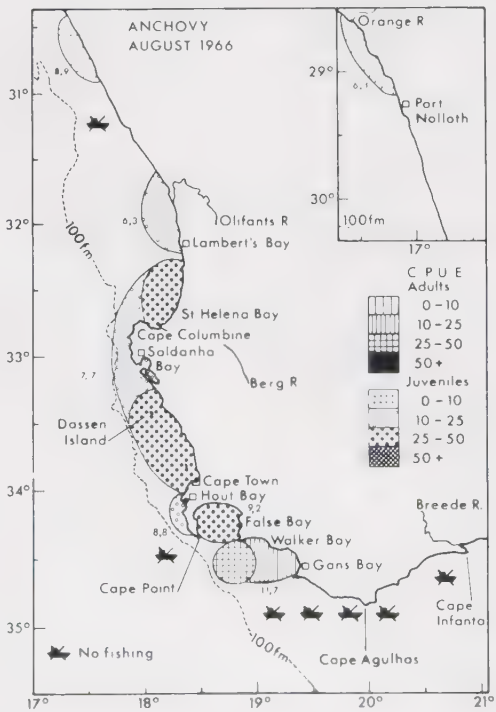
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AUGUST 1966
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Dassen Island
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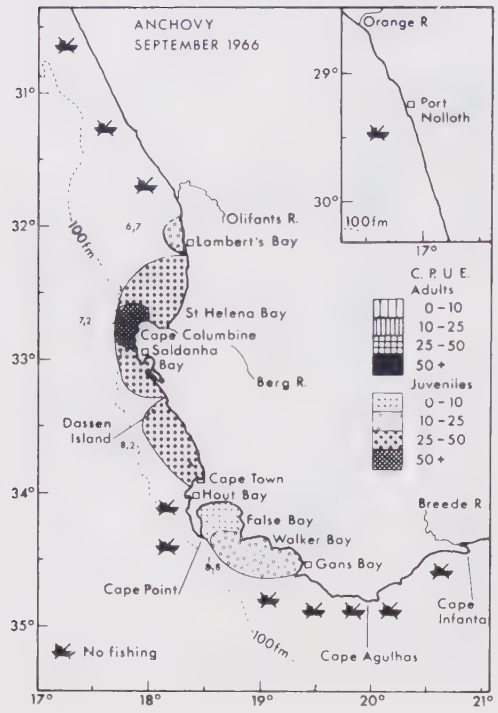
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SEPTEMBER 1966
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Lambert's Bay
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Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Juveniles
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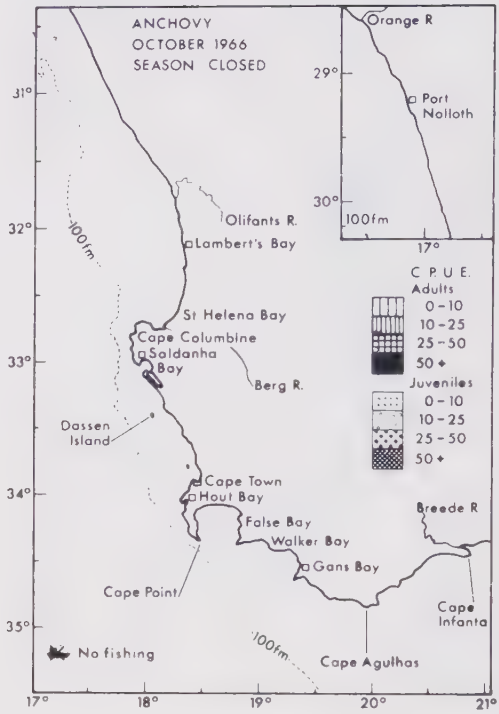
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OCTOBER 1966
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Port Nolloth
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Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
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Cape Point
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Cape Agulhas
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Adults
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Juveniles
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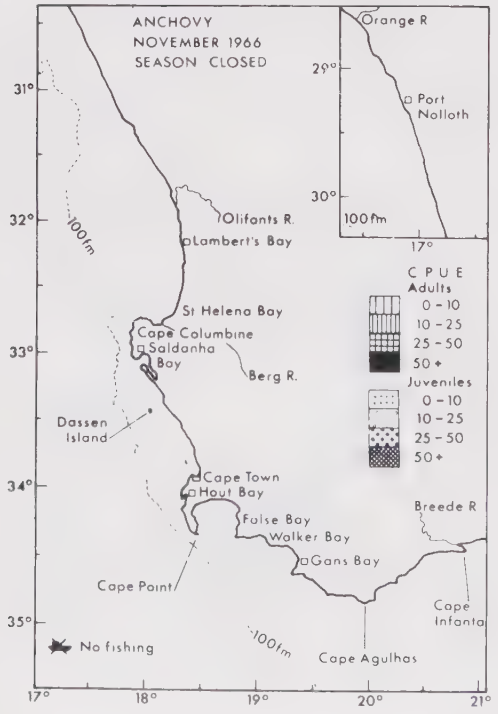
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NOVEMBER 1966
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St Helena Bay
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Saldanha Bay
Berg R.
Dassen Island
Cape Town
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Cape Agulhas
No fishing
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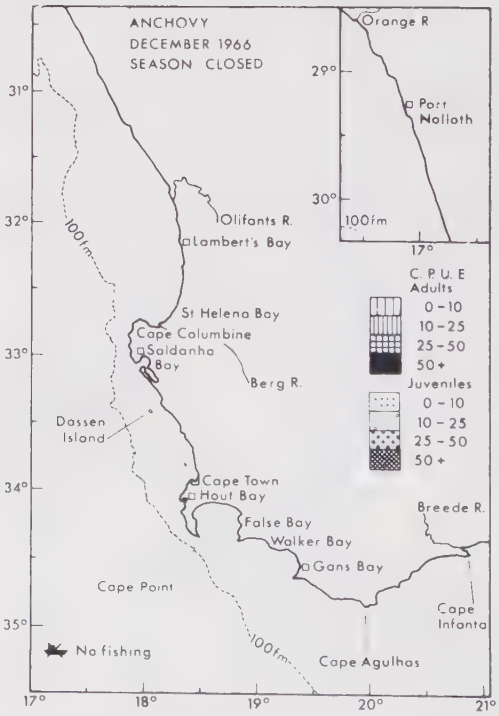
ANCHOVY
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St Helena Bay
Cape Columbine
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Berg R.
Dassen Island
Cape Town
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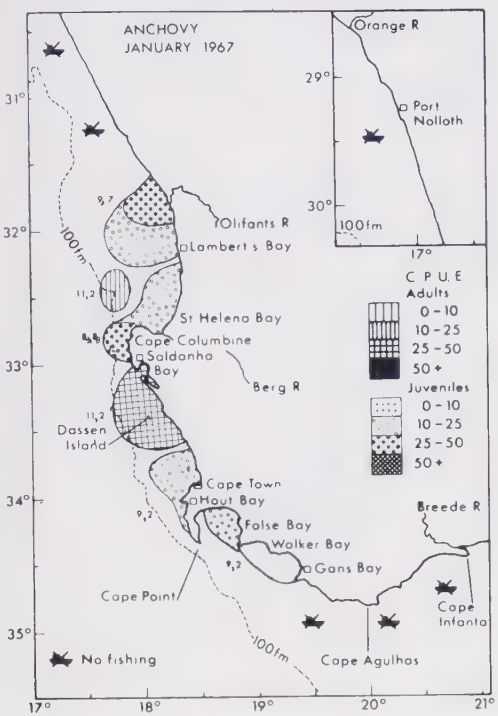
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Saldanha Bay
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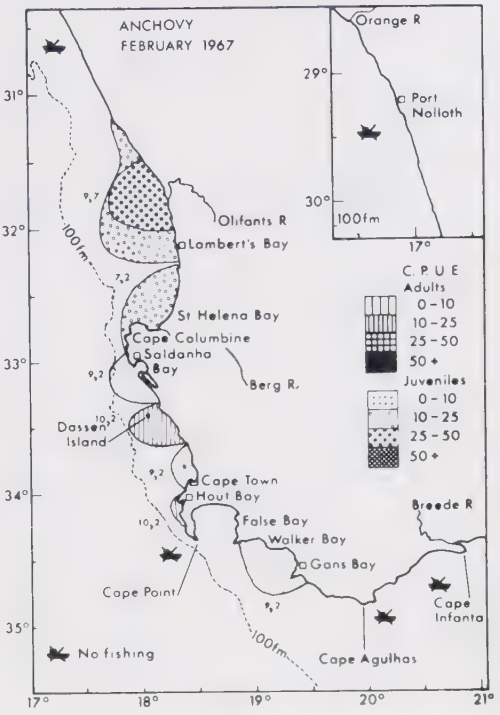
No fishing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FEBRUARY 1967
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Juveniles
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Lambert's Bay
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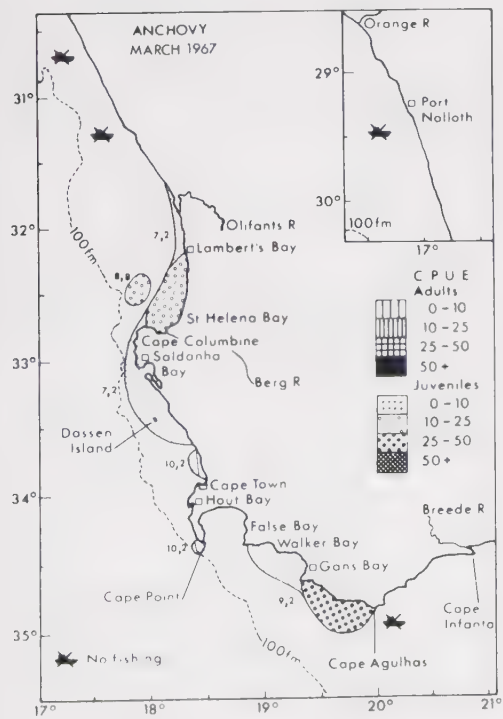
No fishing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MARCH 1967
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Juveniles
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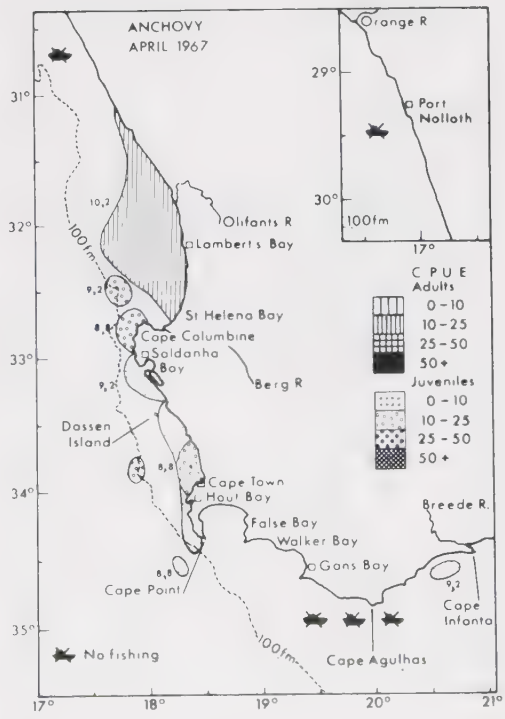
Cape Agulhas
No fishing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100fm
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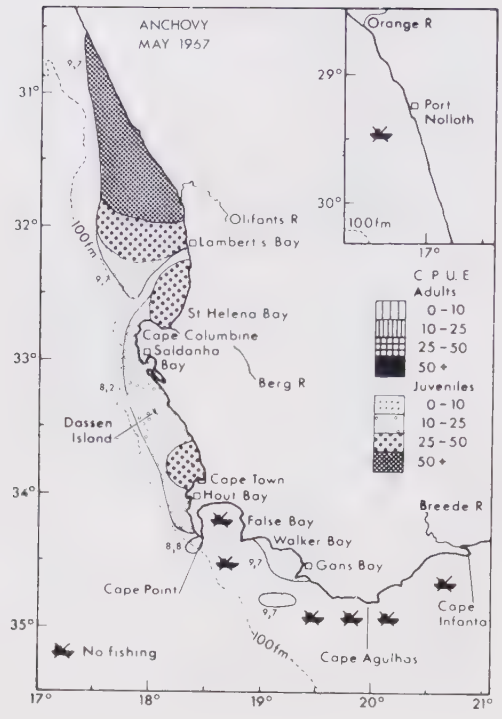
No fishing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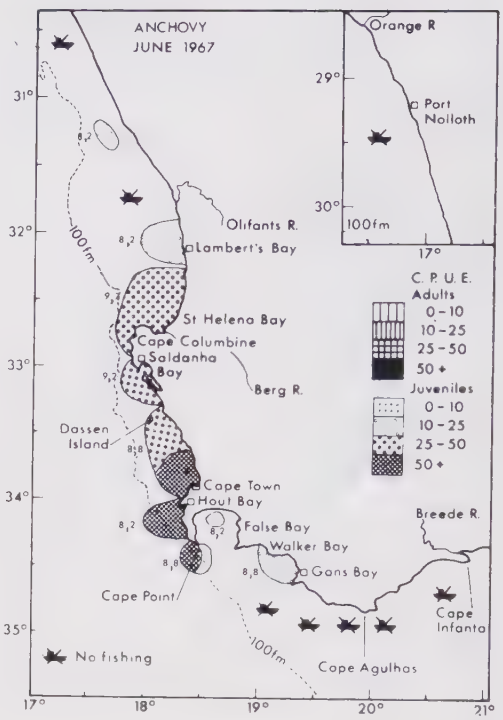
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JUNE 1967
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Port Nolloth
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Lambert's Bay
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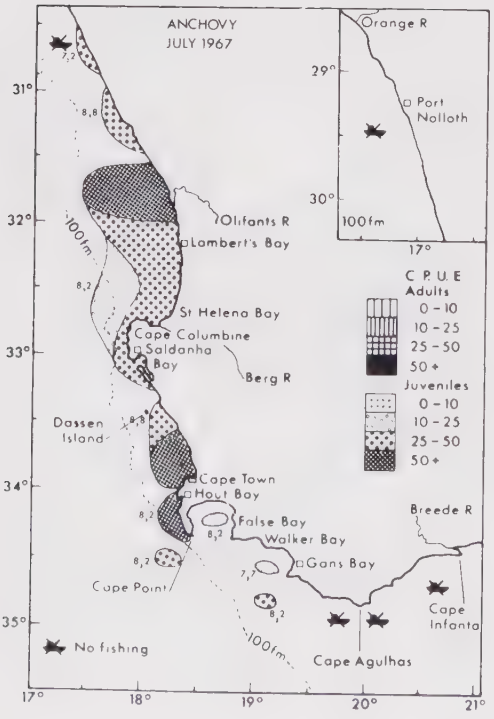
ANCHOVY
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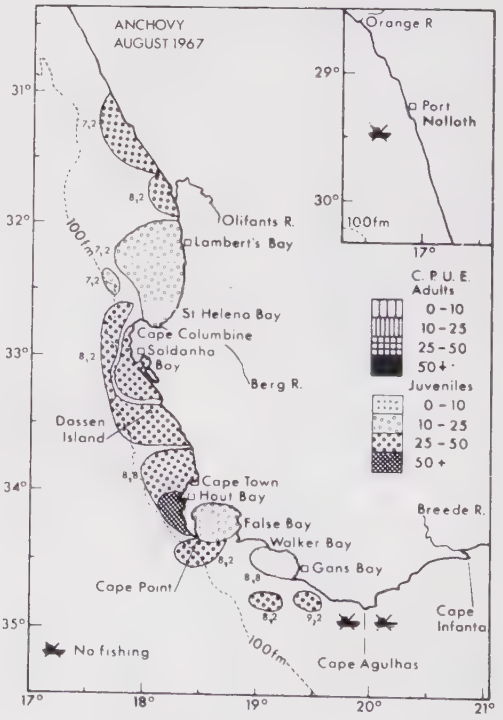
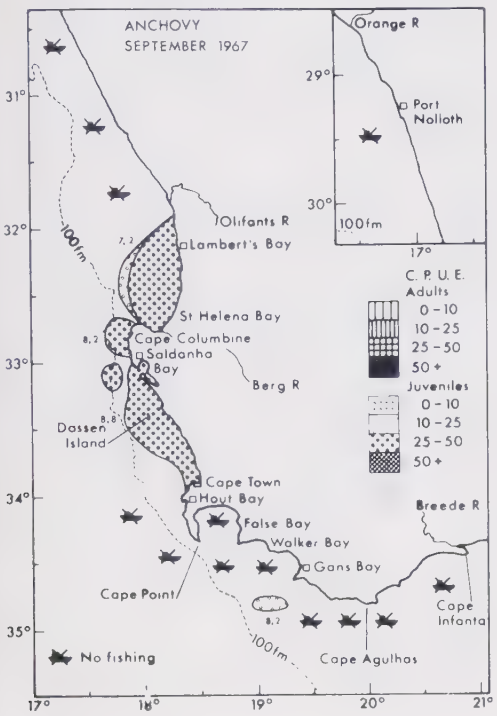

ANCHOVY
AUGUST 1967
Orange R
Port Nolloth
100fm
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C. P. U. E.
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


ANCHOVY
SEPTEMBER 1967
Orange R
Port Nolloth
100fm
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30°
17°
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32°
33°
34°
35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C.P.U.E.
Adults
0-10
10-25
25-50
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Juveniles
0-10
10-25
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50+
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8.8
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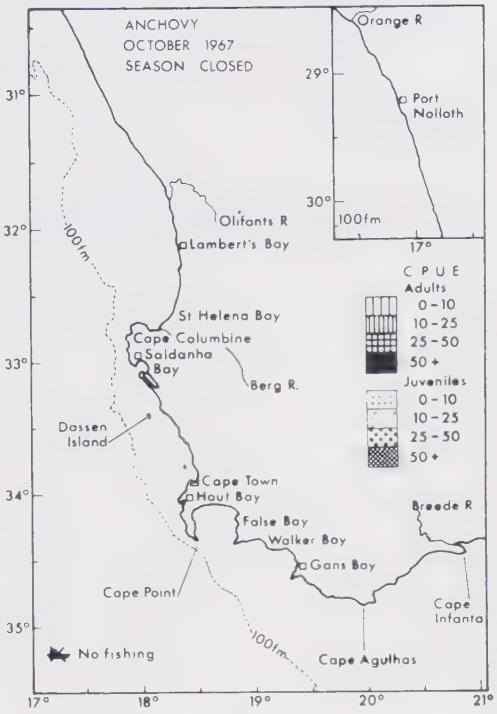
ANCHOVY
OCTOBER 1967
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Port Nolloth
100fm
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35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0-10
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50+
Juveniles
0-10
10-25
25-50
50+
17°
18°
19°
20°
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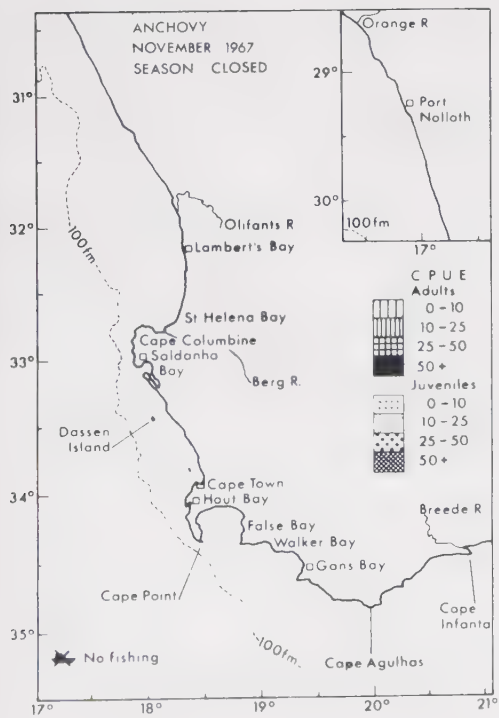
ANCHOVY
NOVEMBER 1967
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0-10
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Juveniles
0-10
10-25
25-50
50+
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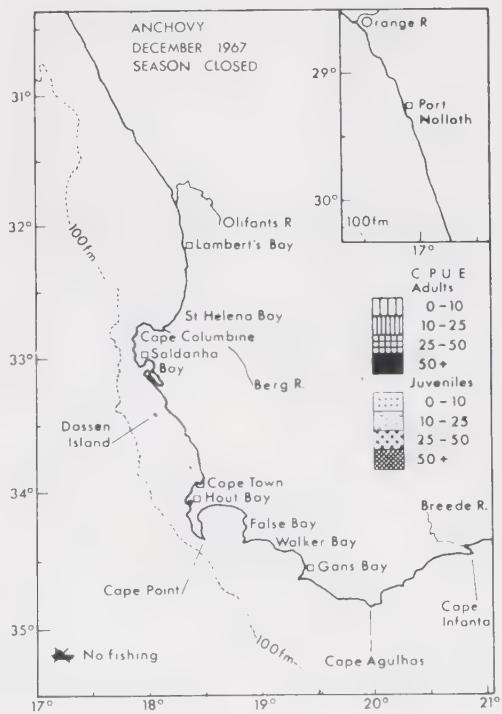
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St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
CPUE
Adults
0-10
10-25
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50+
Juveniles
0-10
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50+
17°
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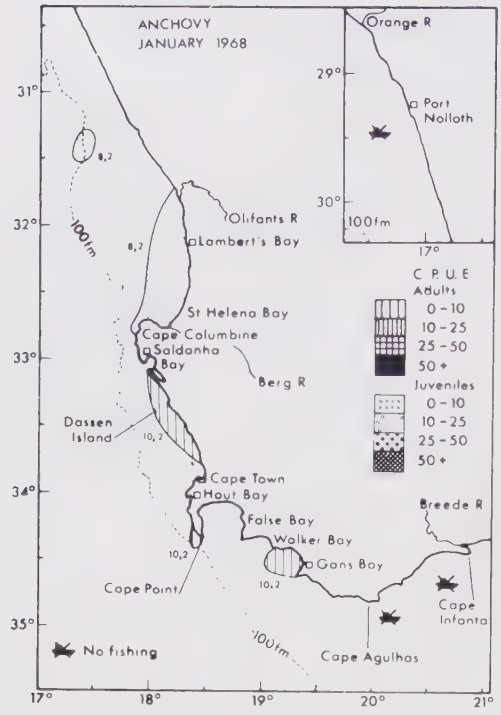
ANCHOVY
JANUARY 1968
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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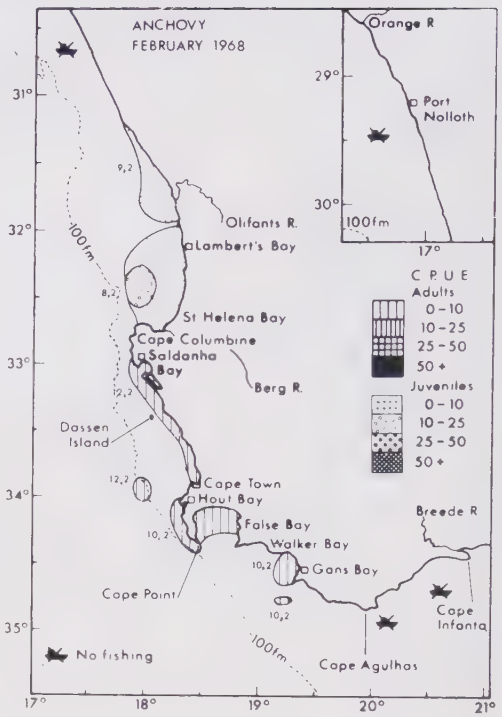
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


ANCHOVY
FEBRUARY 1968
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100fm
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Juveniles
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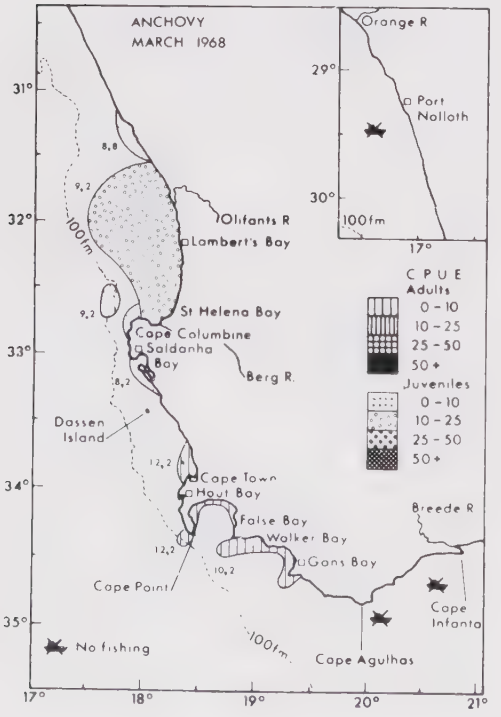
50 +


ANCHOVY
MARCH 1968
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Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
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Juveniles
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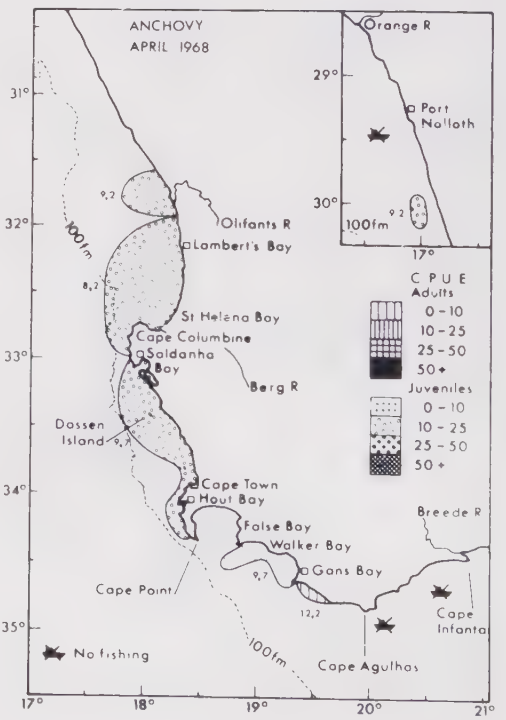
ANCHOVY
APRIL 1968
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Lambert's Bay
St Helena Bay
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Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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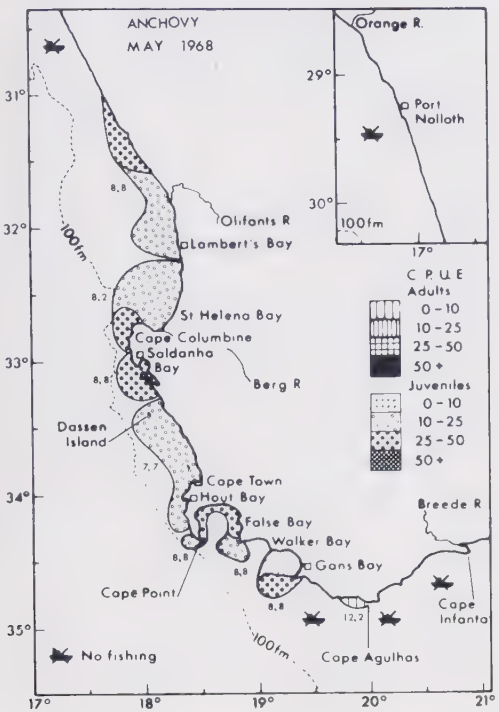
ANCHOVY
MAY 1968
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Port Nolloth
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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Juveniles
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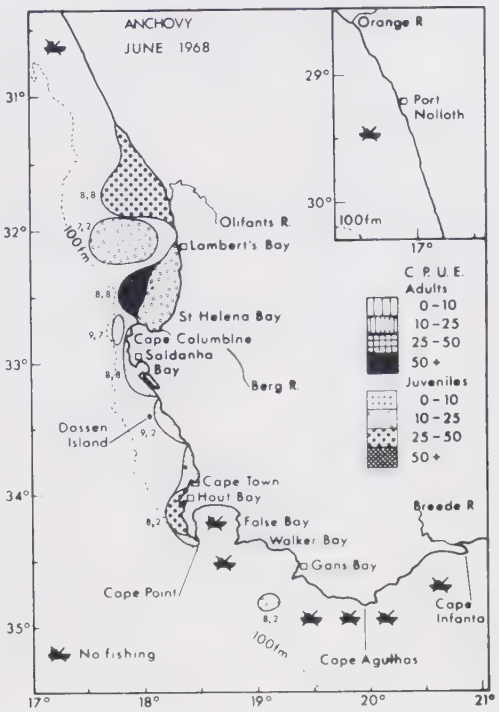
50 +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JUNE 1968
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Lambert's Bay
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Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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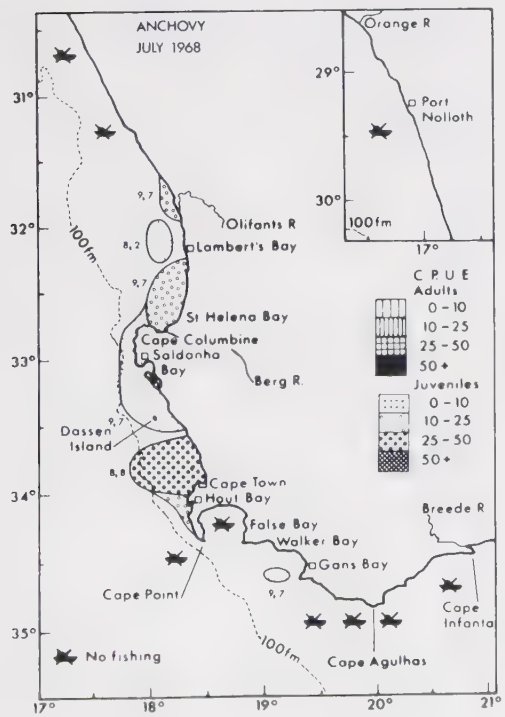
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JULY 1968
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Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
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Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
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Juveniles
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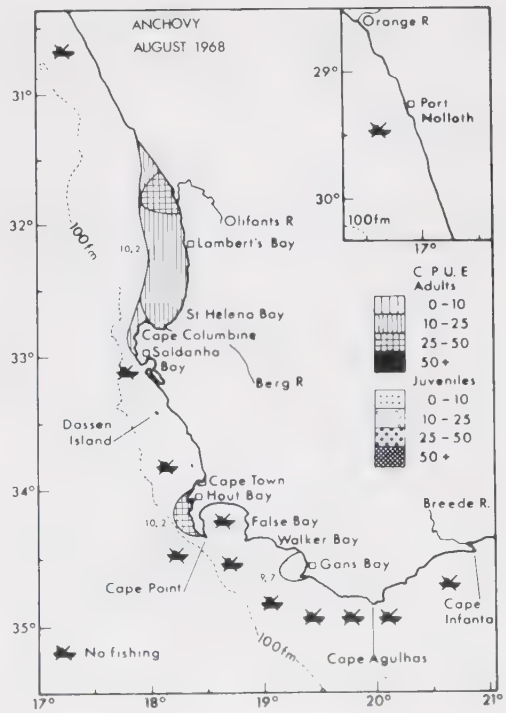
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AUGUST 1968
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Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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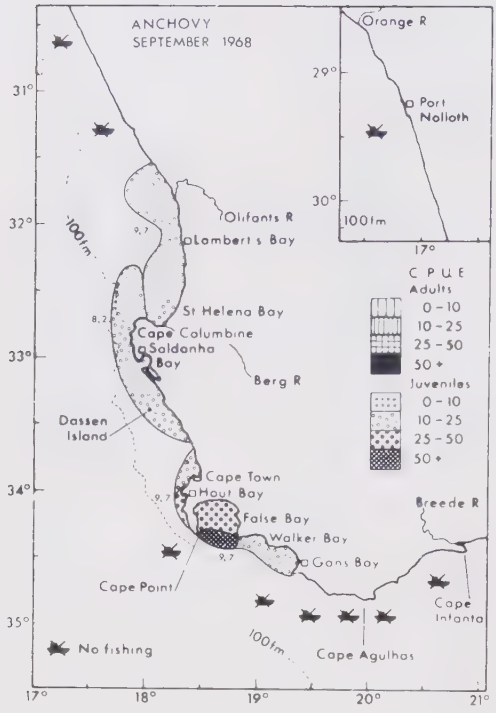
ANCHOVY
SEPTEMBER 1968
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Port Nolloth
29°
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100fm
17°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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50 +
Juveniles
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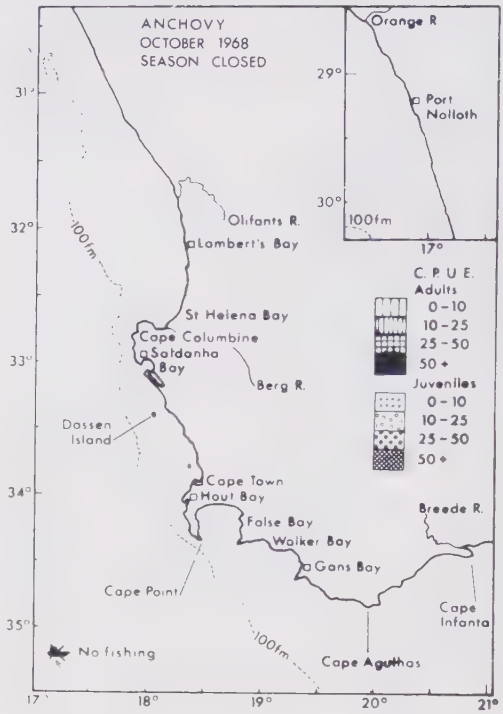
ANCHOVY
OCTOBER 1968
SEASON CLOSED
Orange R
Port Nolloth
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100fm
17°
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C. P. U. E.
Adults
0 - 10
10 - 25
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50 +
Juveniles
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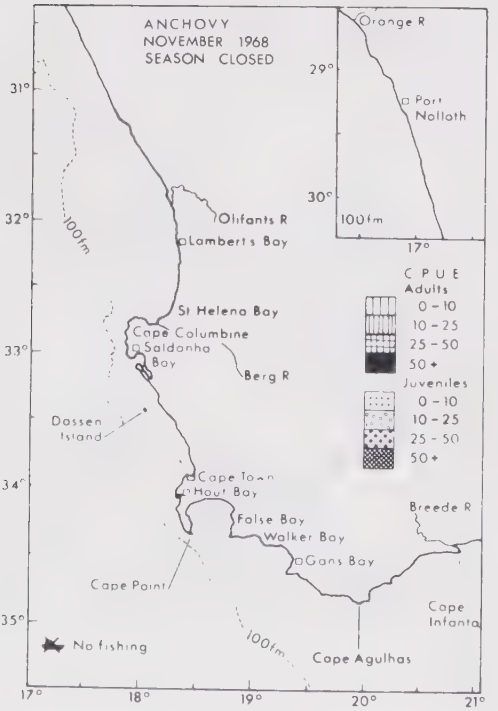
ANCHOVY
NOVEMBER 1968
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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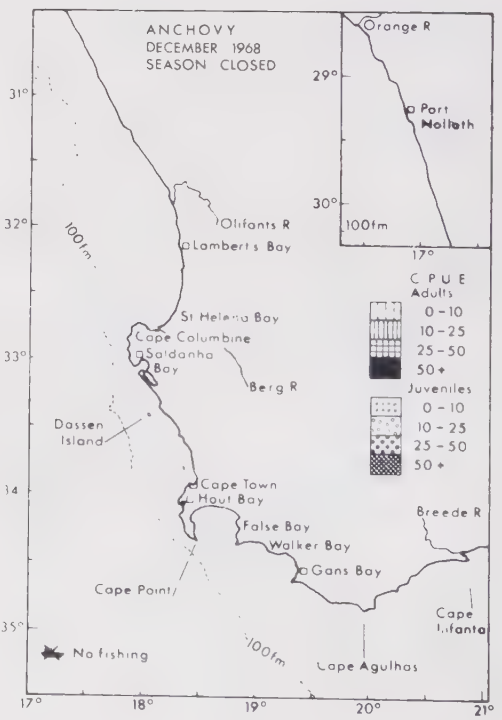
ANCHOVY
DECEMBER 1968
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Orange R
Port Nolloth
29°
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
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No fishing
C P U E
Adults
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Juveniles
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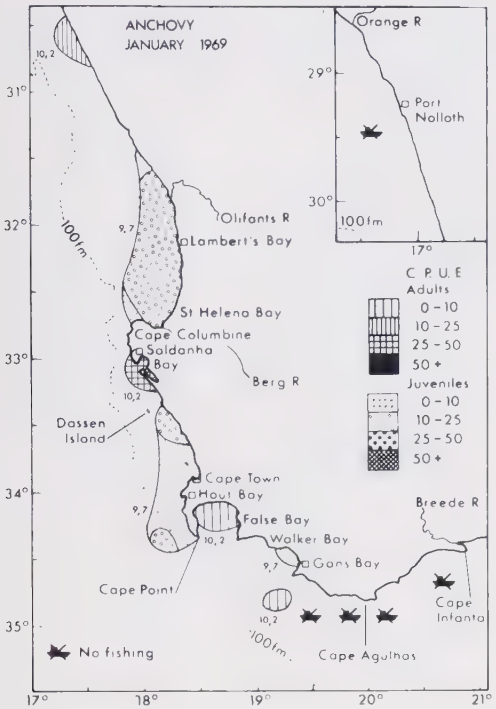
ANCHOVY
JANUARY 1969
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Port Nolloth
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Cape Infanta
Cape Agulhas
No fishing
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Juveniles
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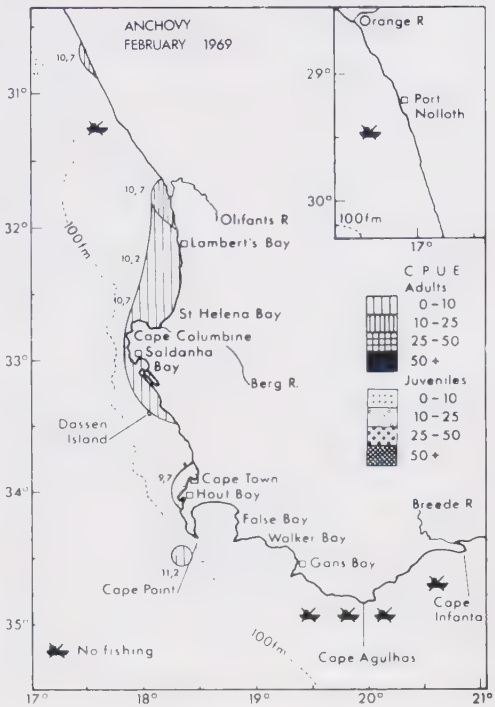
ANCHOVY
FEBRUARY 1969
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Lambert's Bay
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Berg R.
Dassen Island
Cape Town
Hout Bay
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Walker Bay
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Cape Point
Cape Infanta
Cape Agulhas
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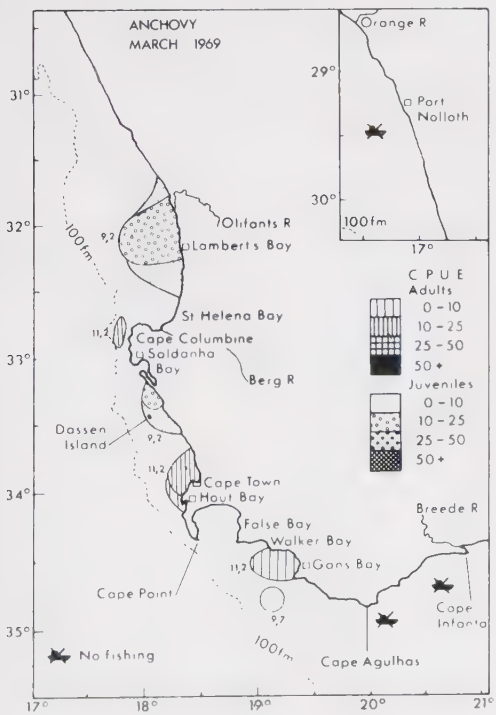
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Berg R
Dassen Island
Cape Town
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False Bay
Walker Bay
Gans Bay
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Cape Infanta
Cape Agulhas
No fishing
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Juveniles
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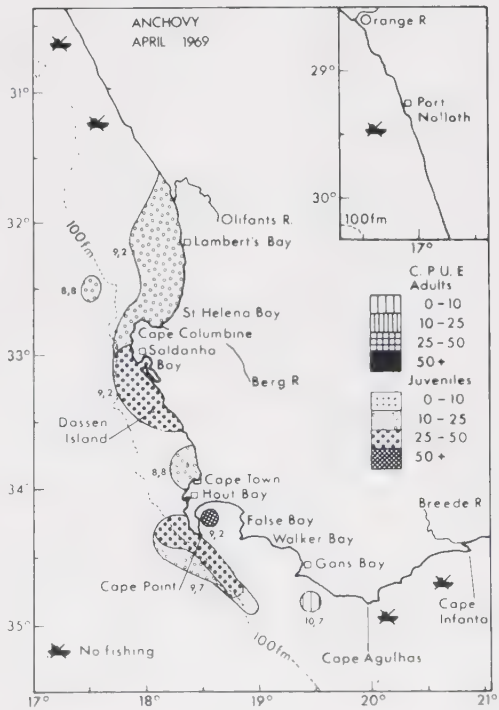
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Juveniles
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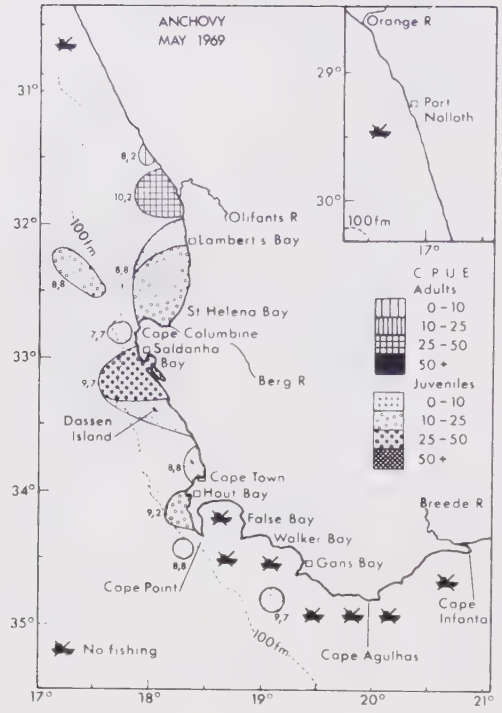
ANCHOVY
MAY 1969
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St Helena Bay
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Dassen Island
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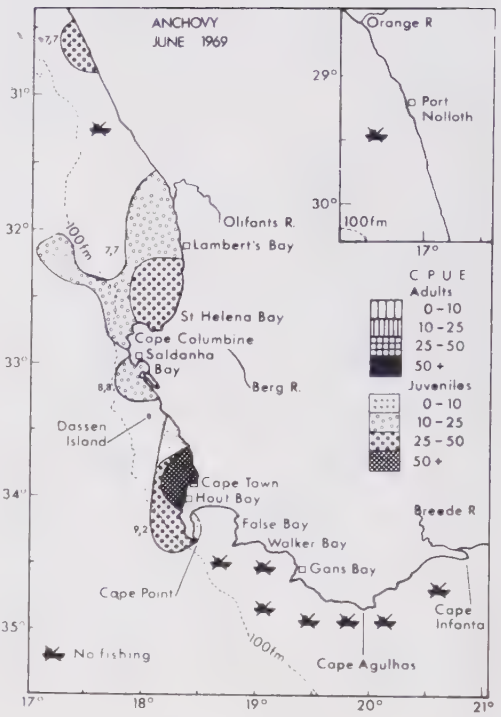
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JUNE 1969
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Dassen Island
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Breede R
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Juveniles
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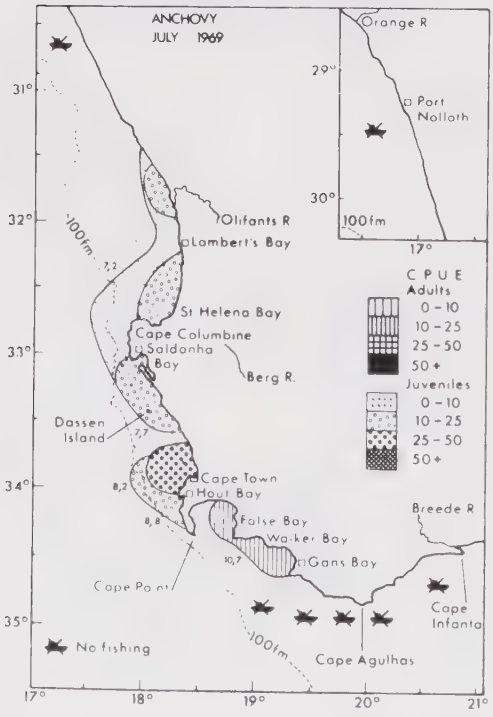
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Juveniles
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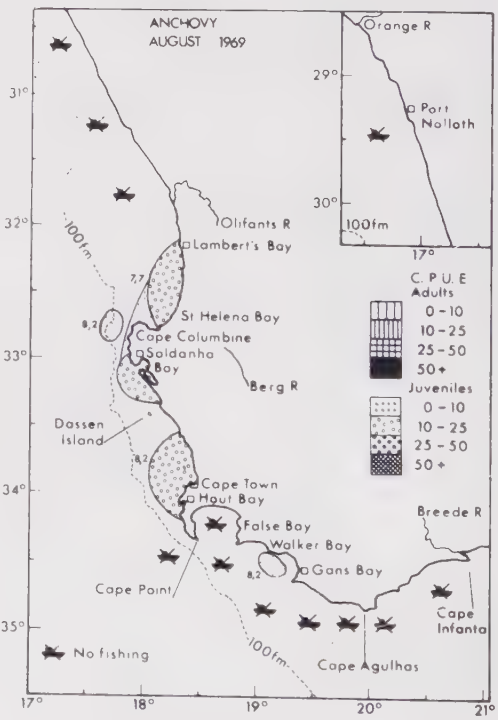
ANCHOVY
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Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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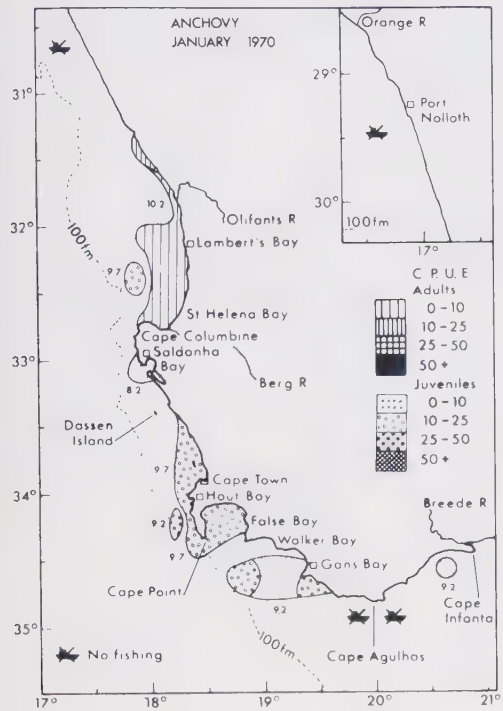
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Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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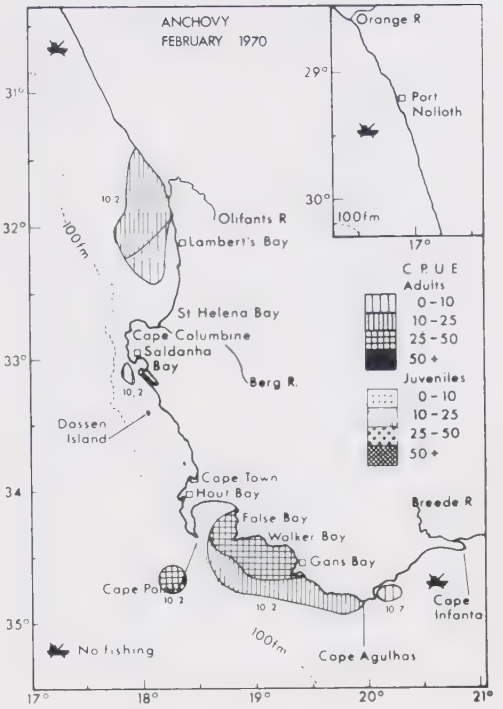
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Dassen Island
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Cape Agulhas
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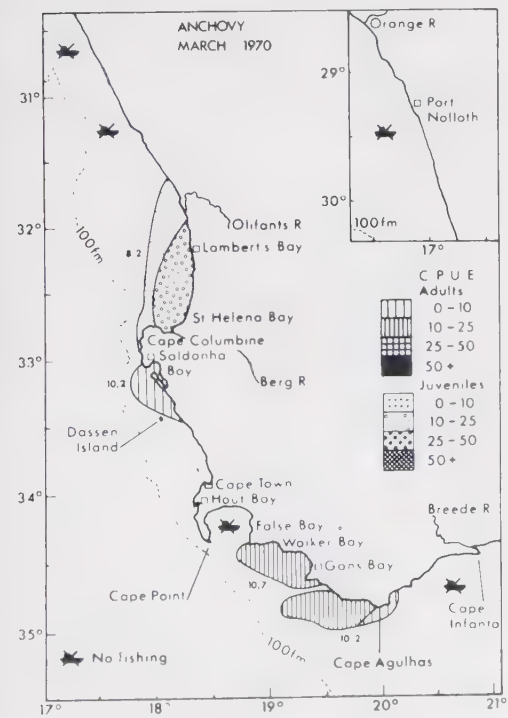
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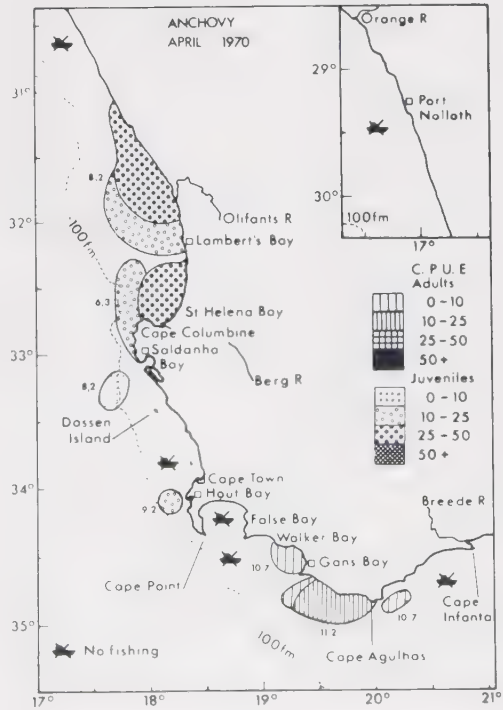
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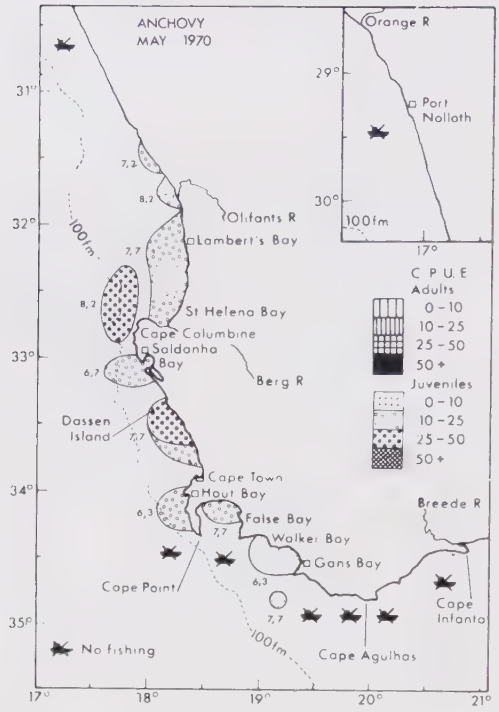
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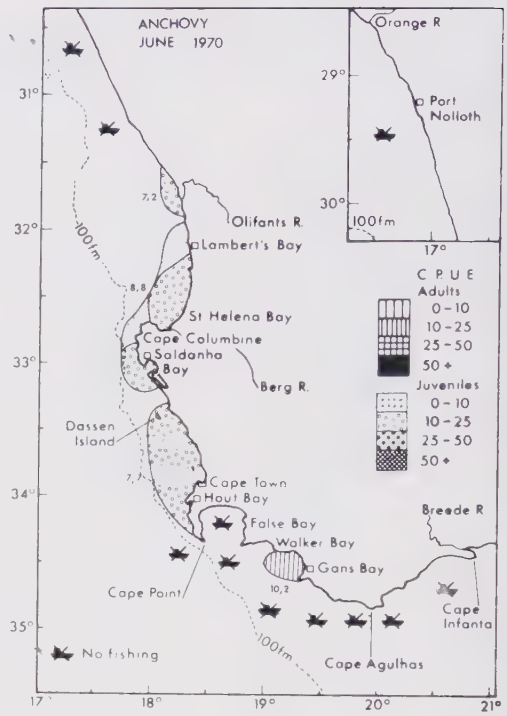
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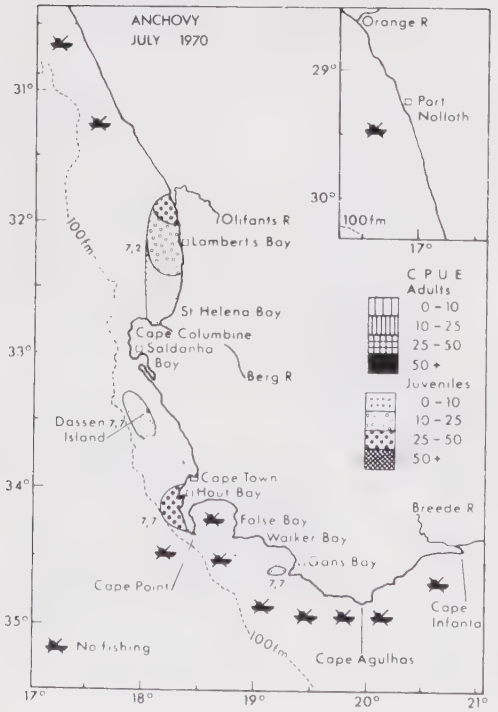
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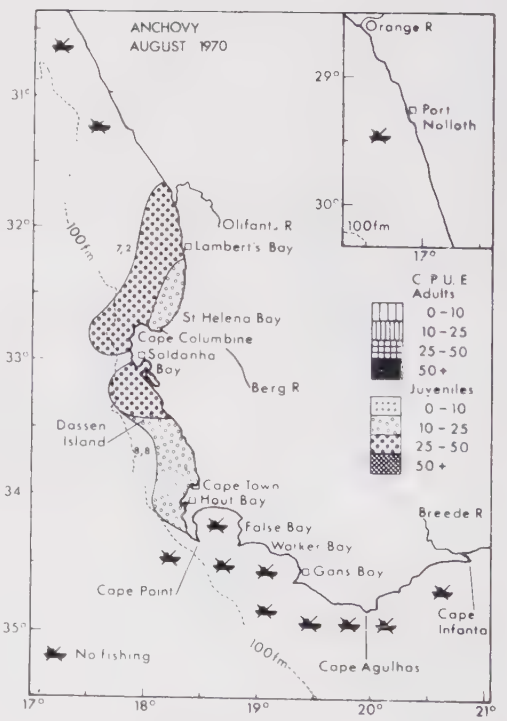
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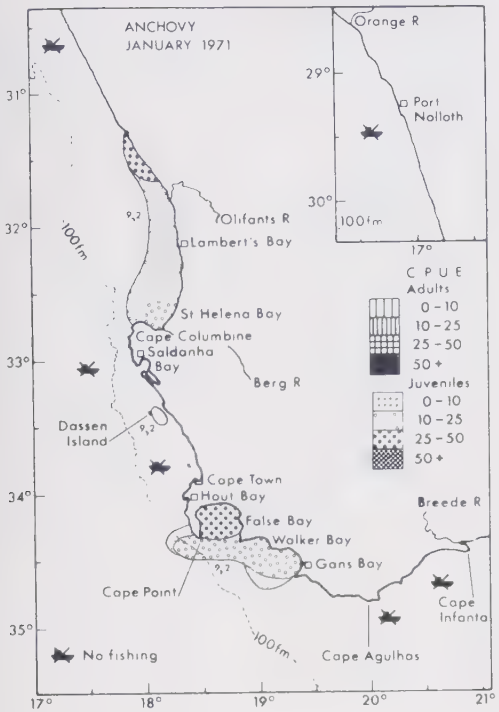
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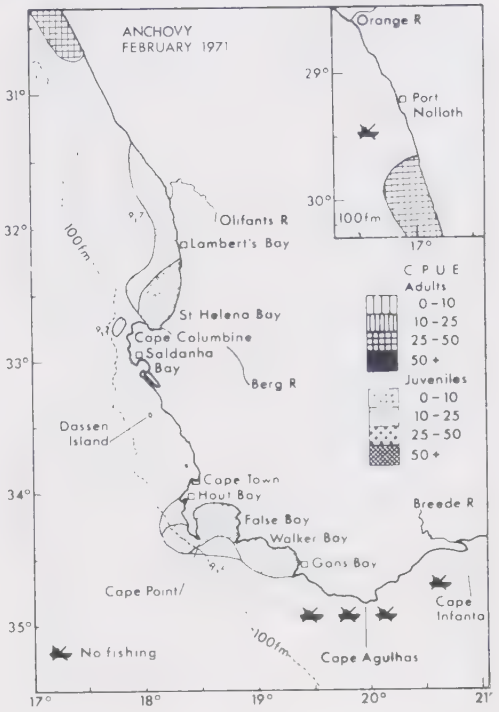
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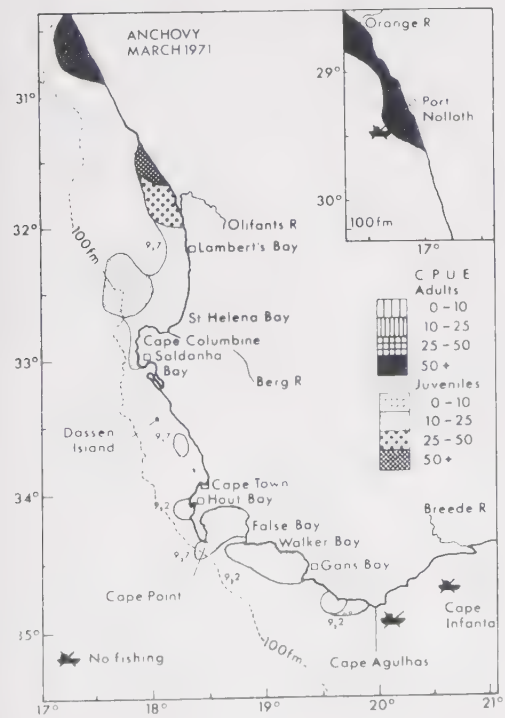
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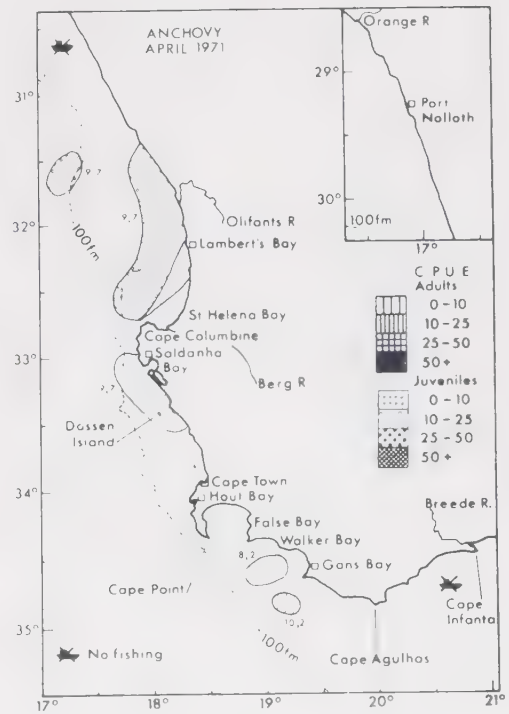
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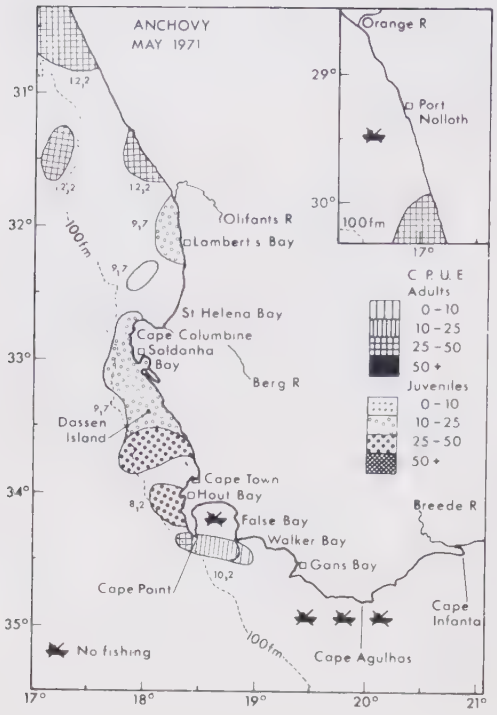
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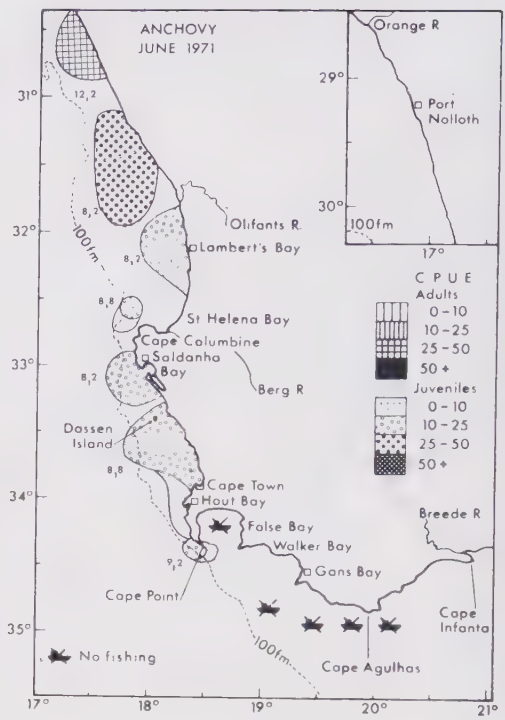
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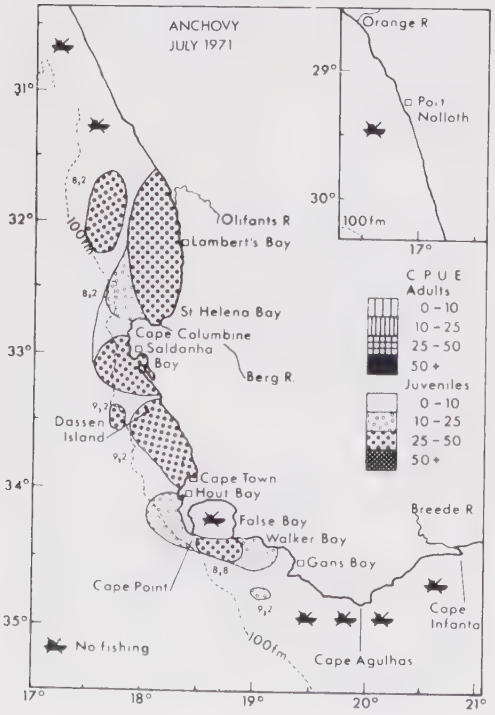
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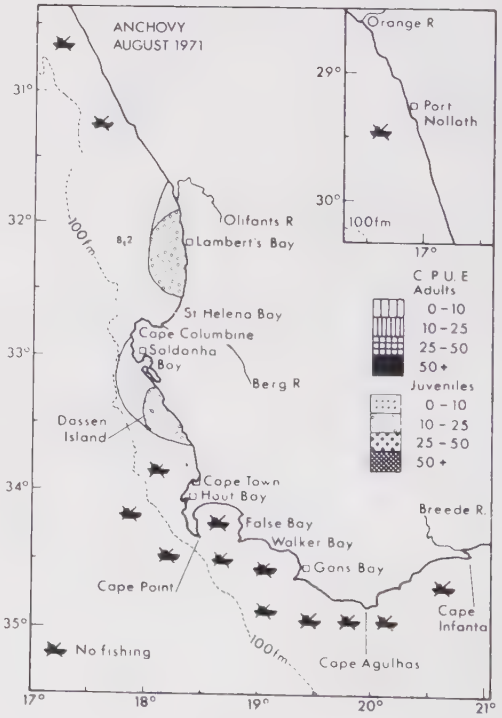
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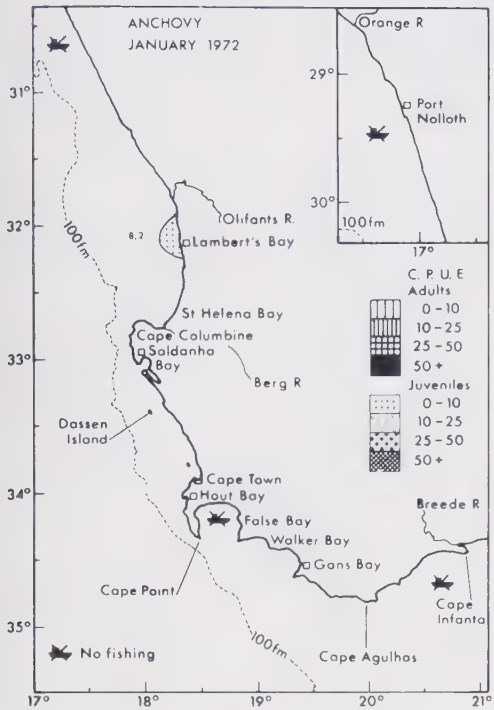
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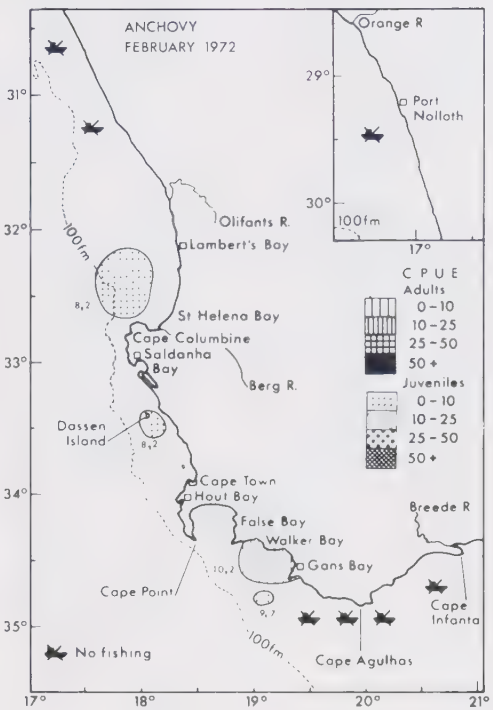
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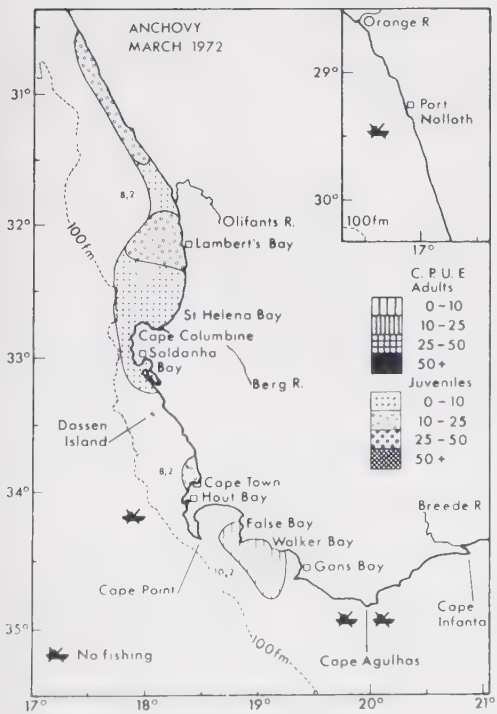
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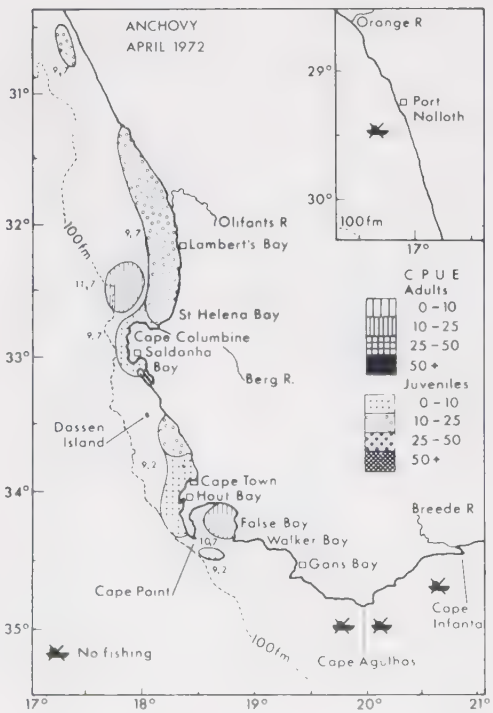
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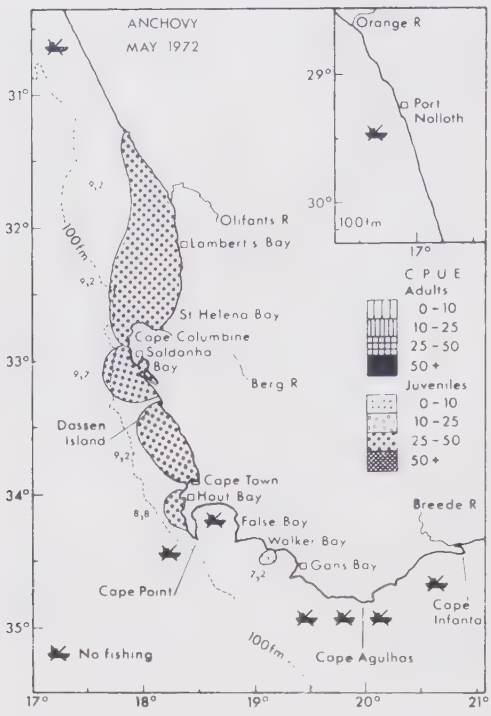
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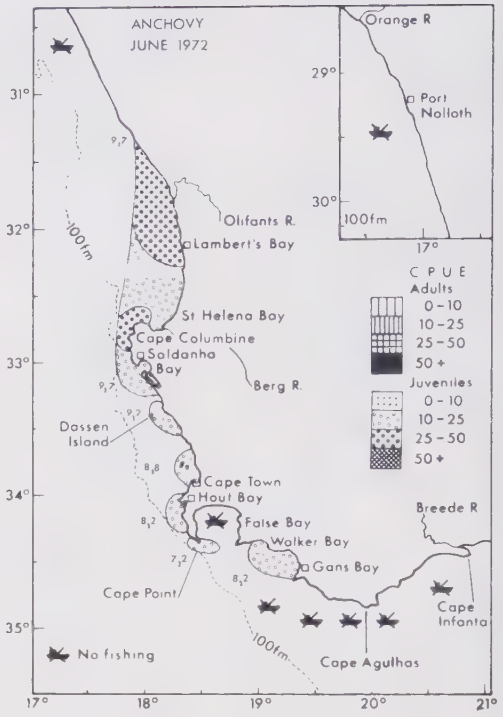
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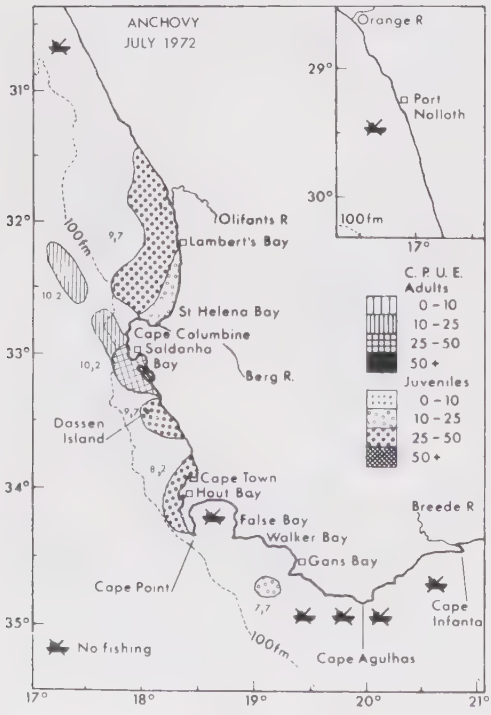
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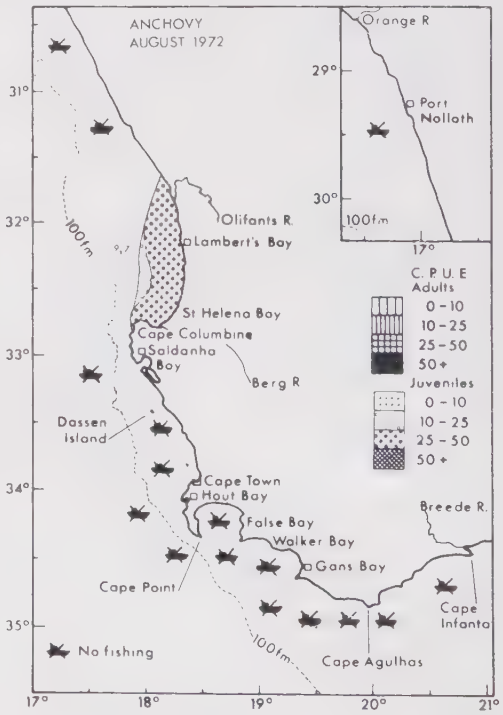
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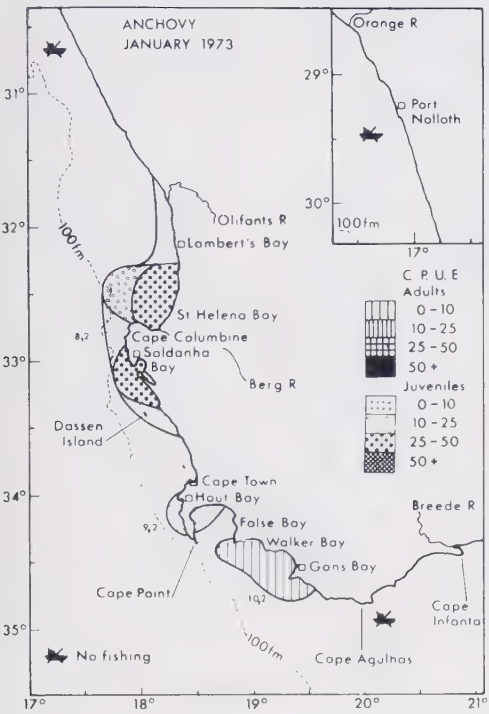
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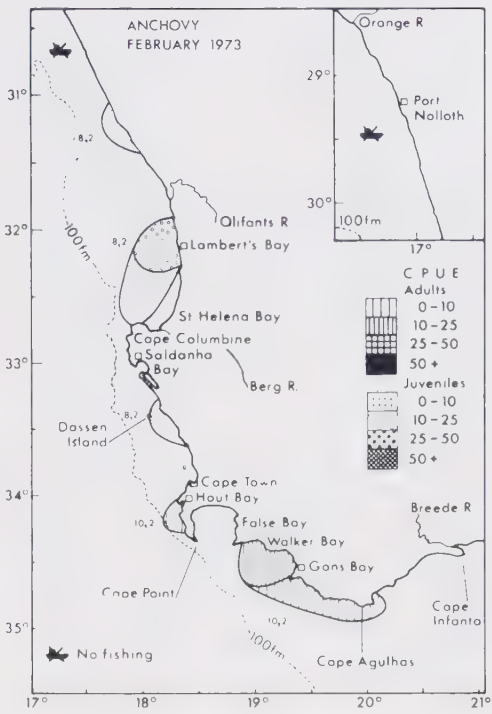
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Port Nolloth
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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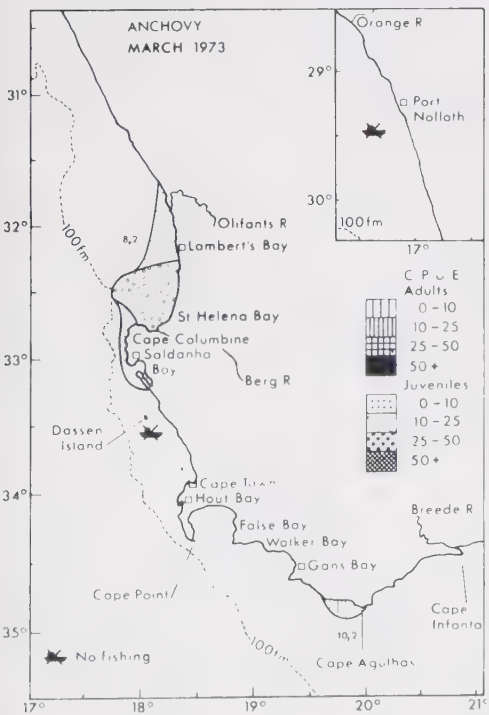
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St Helena Bay
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Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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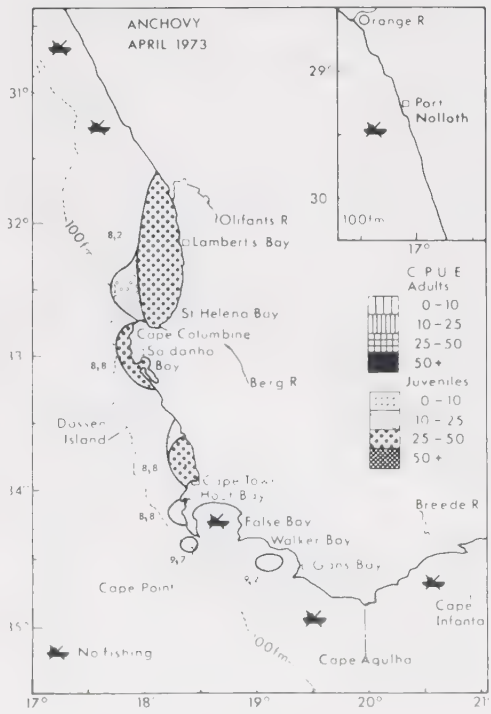
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Dassen Island
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Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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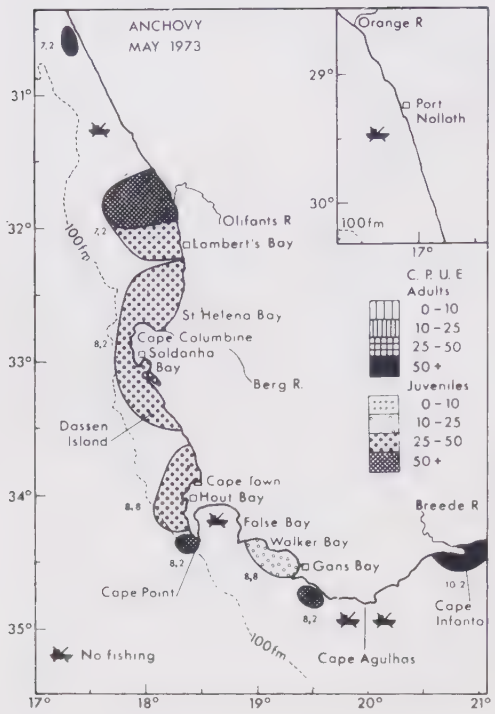
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Dassen Island
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Walker Bay
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No fishing
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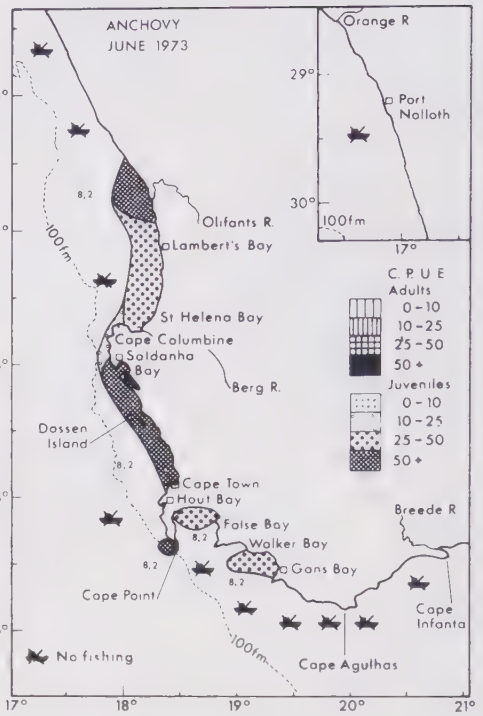
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JUNE 1973
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Dassen Island
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No fishing
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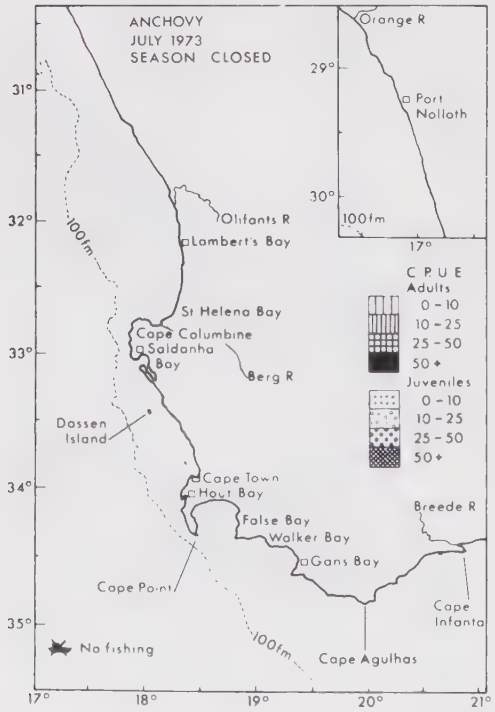
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JULY 1973
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
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Saldanha Bay
Berg R
Dassen Island
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No fishing
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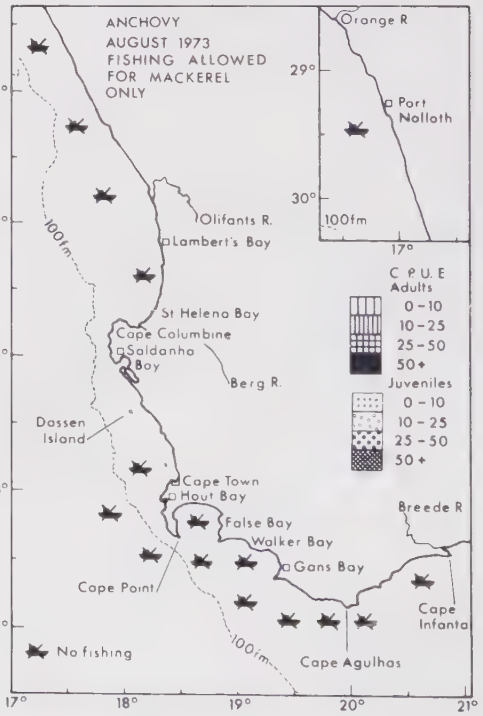
ANCHOVY
AUGUST 1973
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Port Nolloth
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Lambert's Bay
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Saldanha Bay
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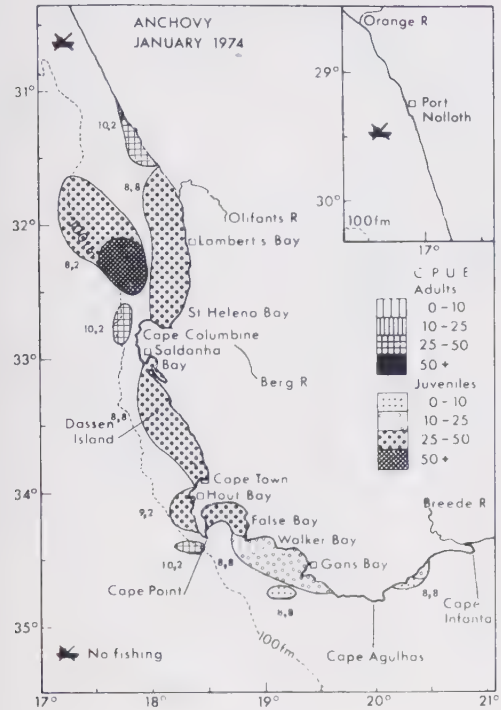
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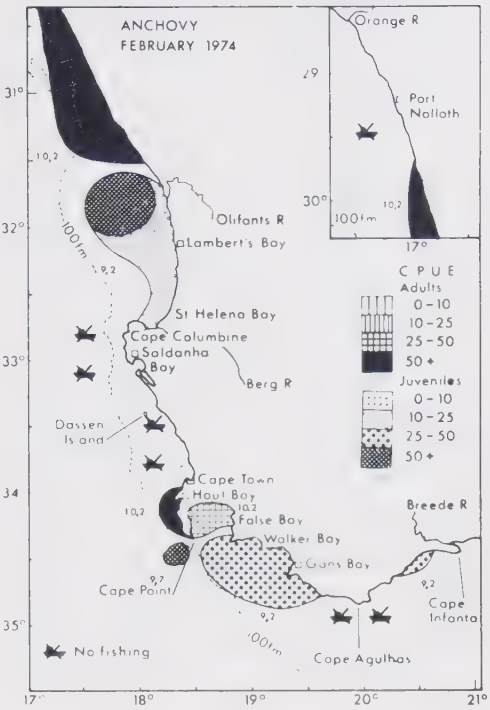
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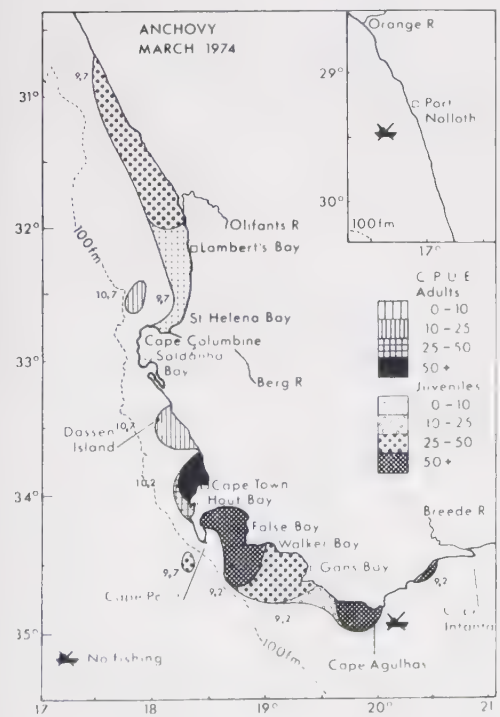
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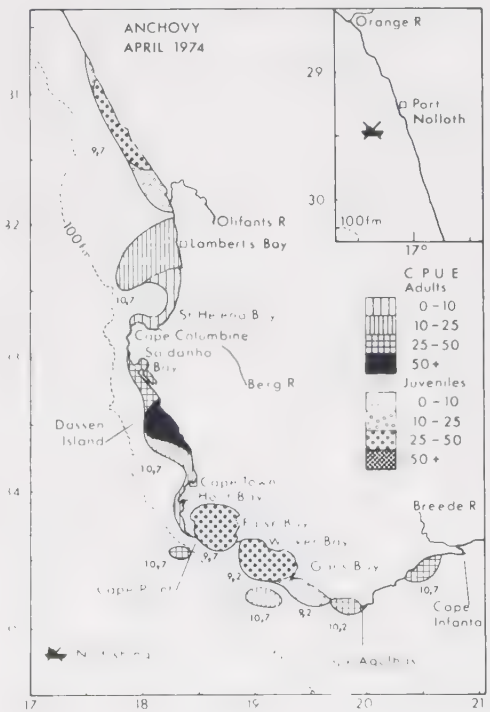
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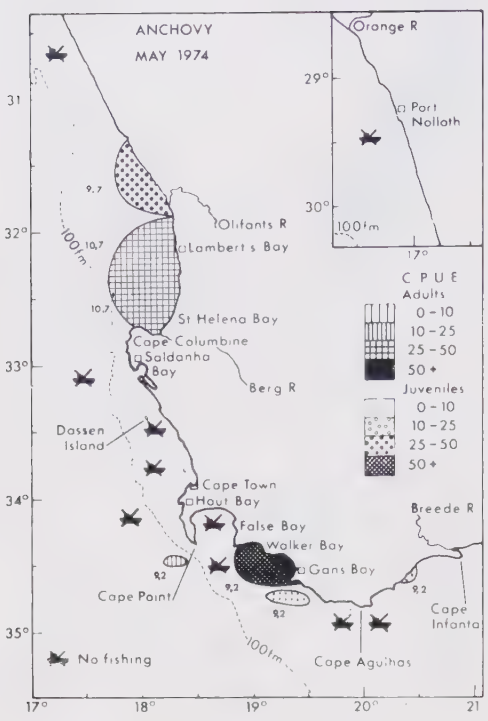
ANCHOVY
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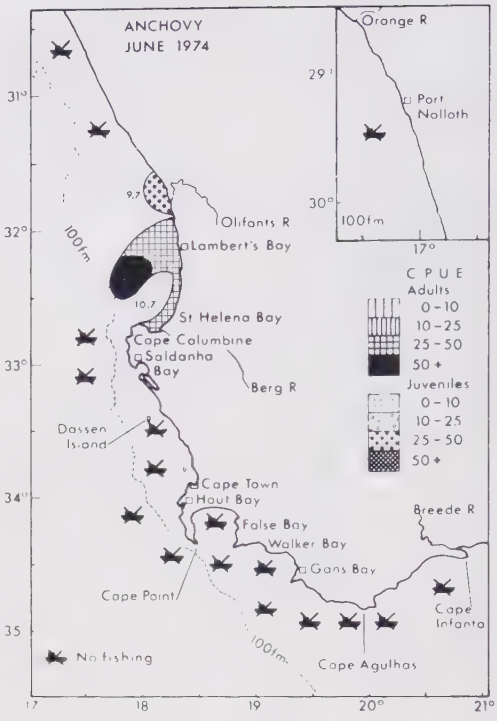
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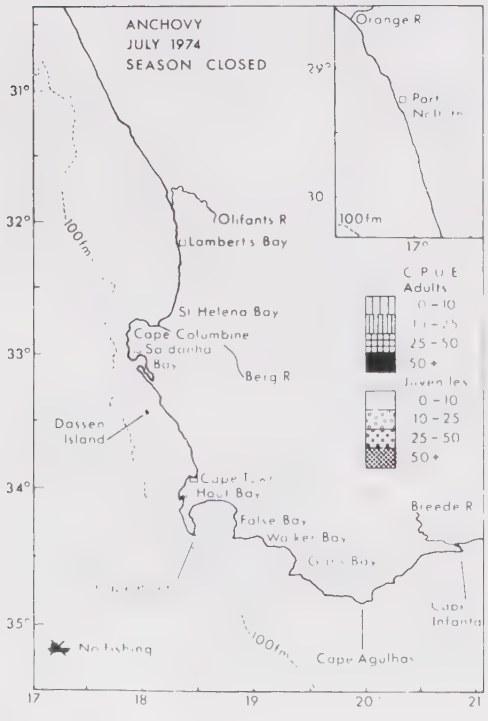
ANCHOVY
JULY 1974
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Lambert's Bay
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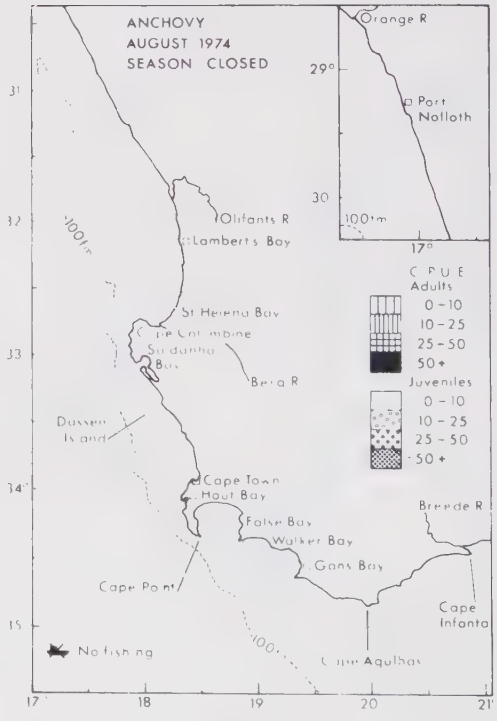
ANCHOVY
AUGUST 1974
SEASON CLOSED
Orange R
Port Nolloth
Olifants R
Lambert's Bay
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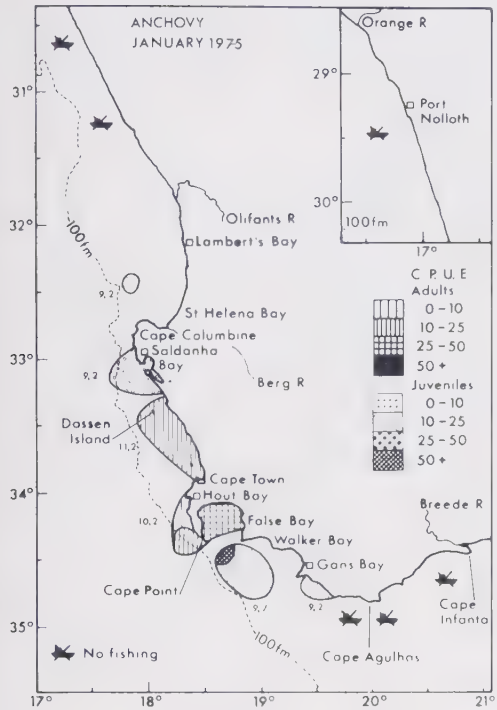
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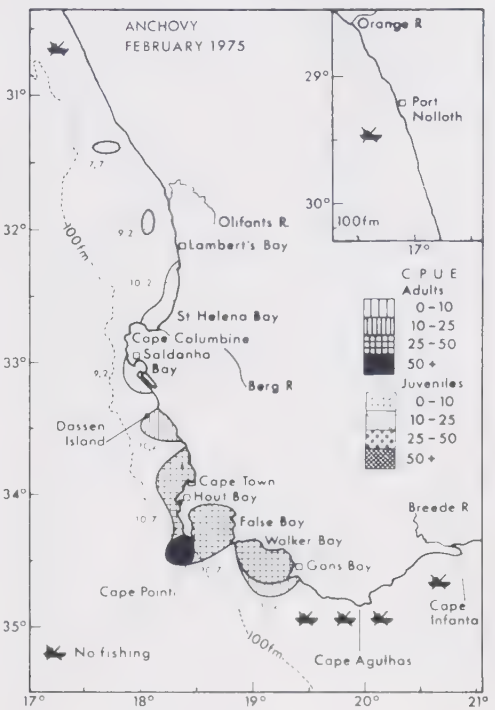
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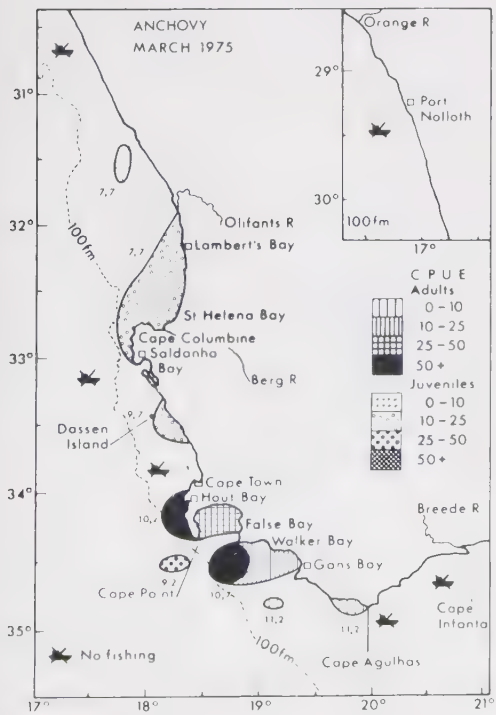
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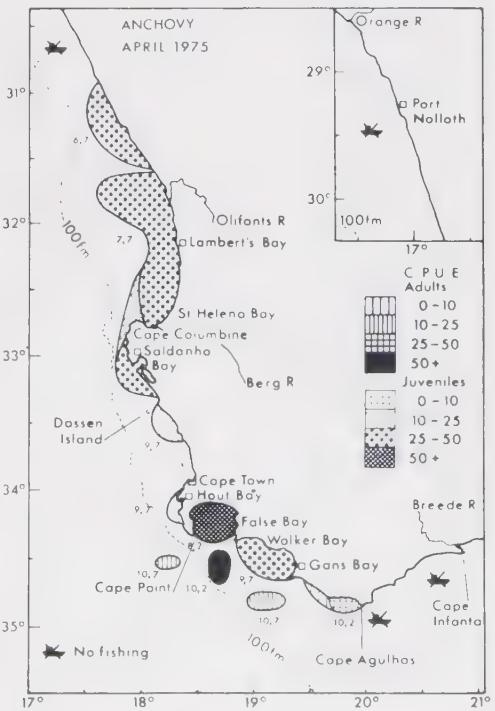
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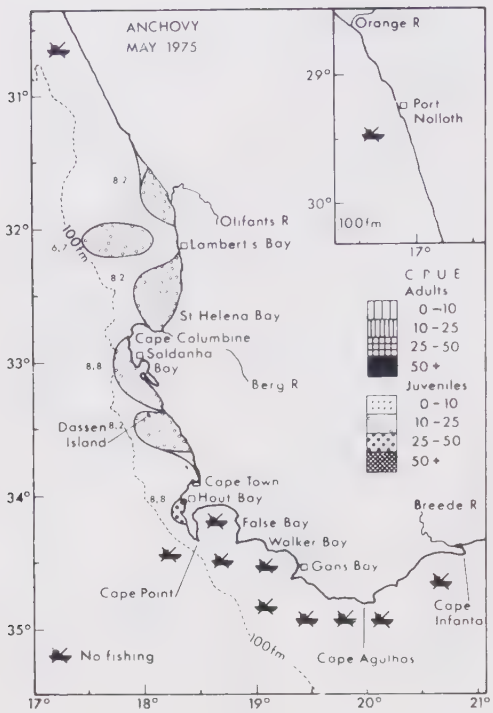
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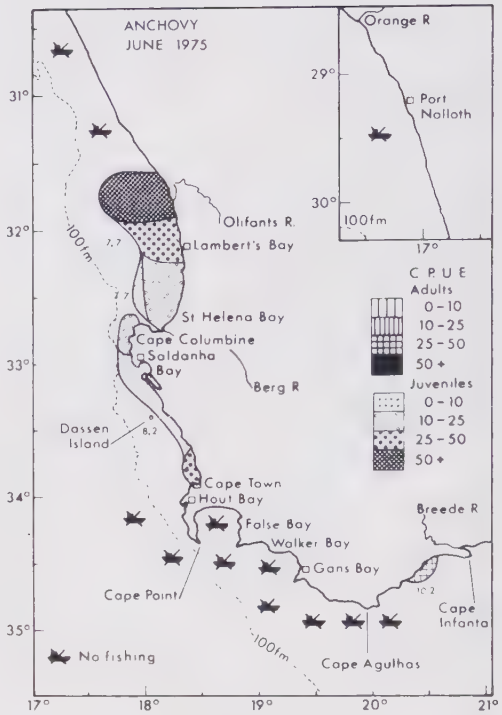
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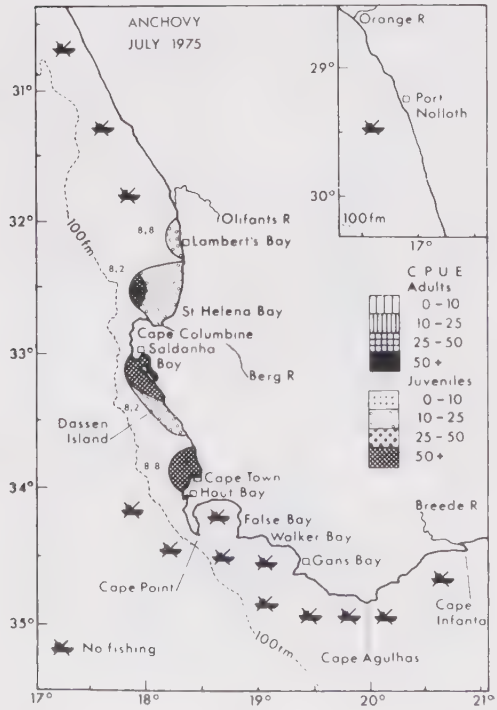
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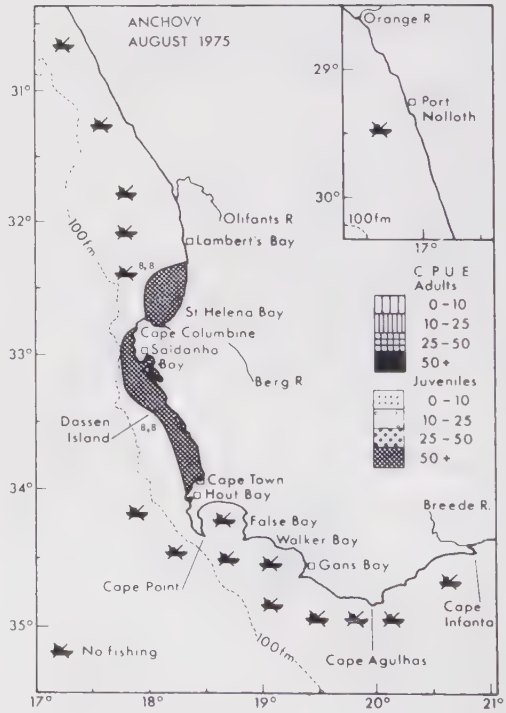
ANCHOVY
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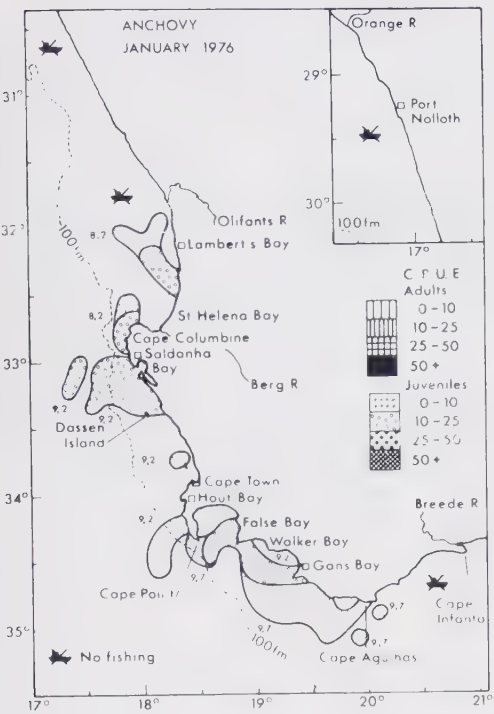
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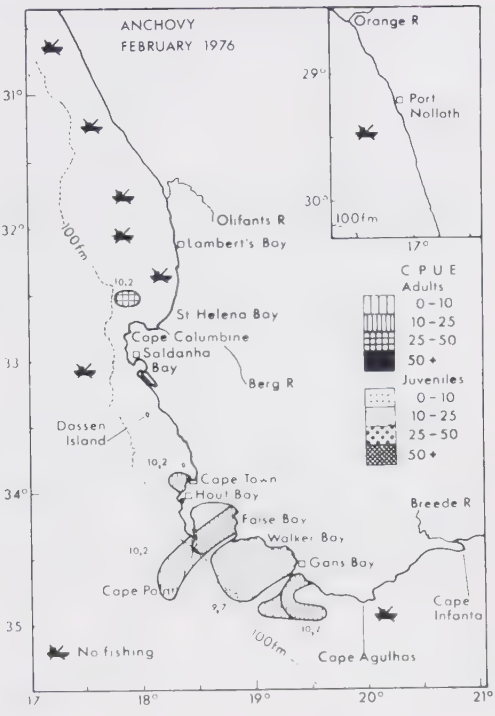
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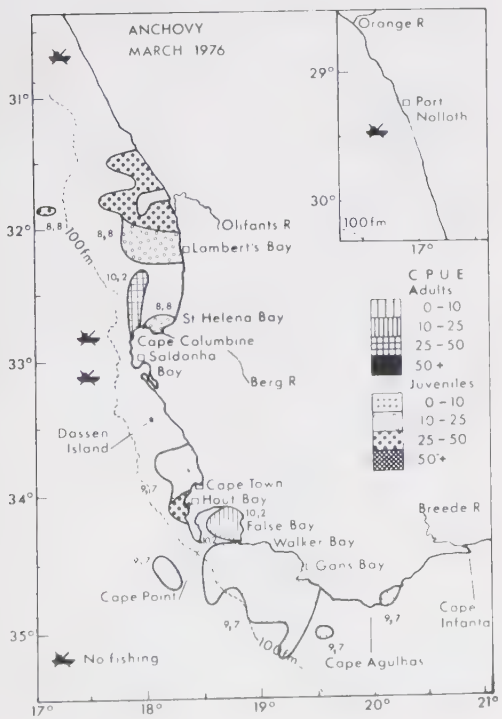
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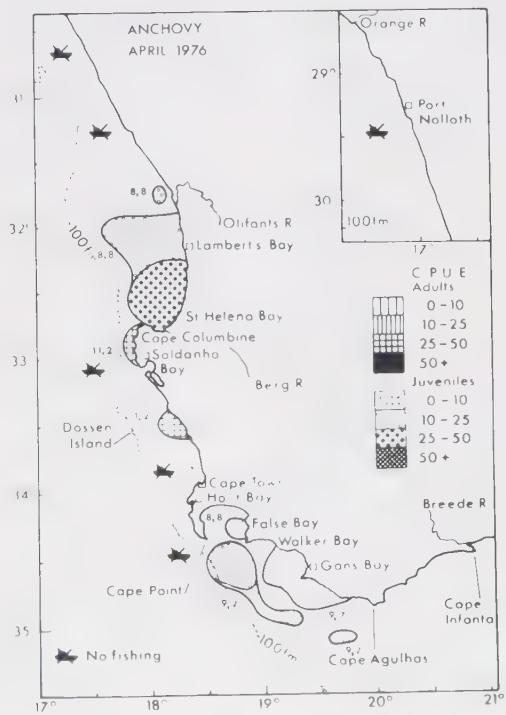
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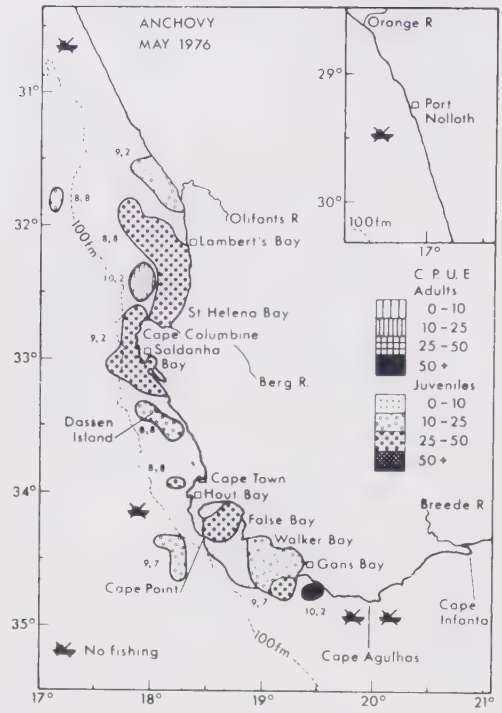
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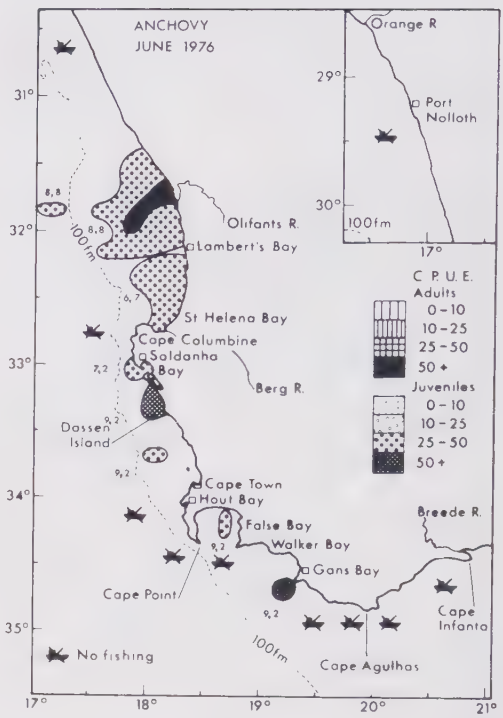
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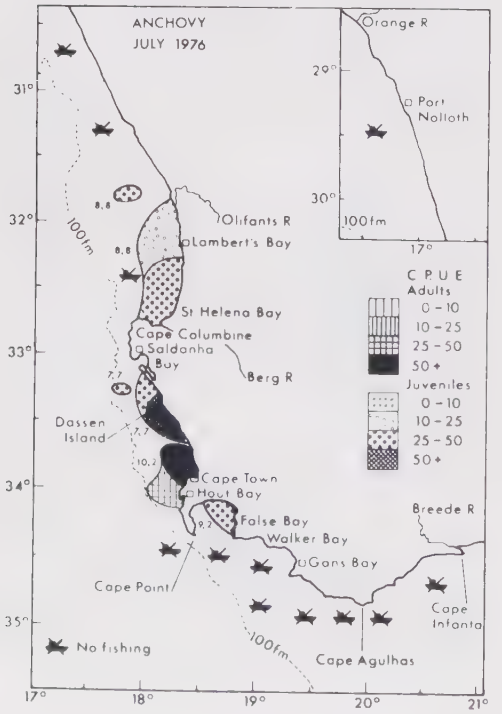
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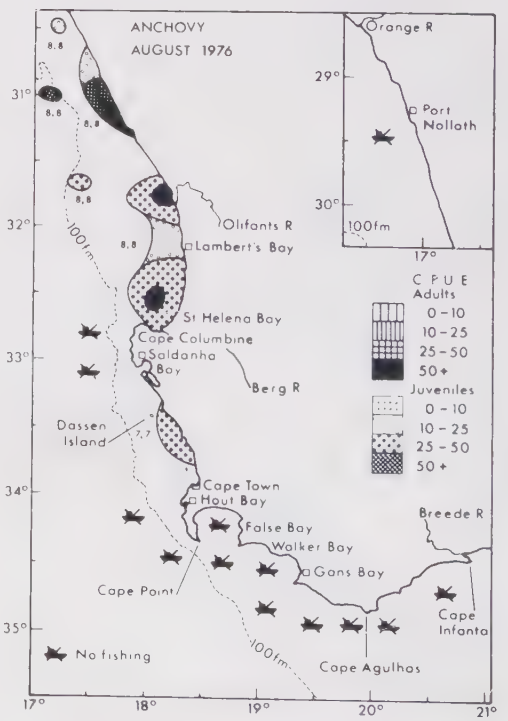
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ANALYSIS OF CHLOROPHYLL *A* IN PARTICULATE MATTER

M. J. SWART AND R. G. BARLOW

A procedure to determine total chlorophyll *a* and active chlorophyll *a* in particulate matter is described. Pigments were extracted in 90-per-cent acetone and total chlorophyll *a* determined from absorbance measurements at 665 nm. Active chlorophyll *a* was extracted into hexane by partitioning pigments between aqueous acetone and hexane according to the method of Whitney and Darley (1979). Absorbance measurements at 663 nm were made on the hexane extract before and after acidification with 5N hydrochloric acid and the decrease in absorbance was used to determine the amount of active chlorophyll *a*. Calibration curves, prepared with pure chlorophyll *a* standards, were used in the calculation of chlorophyll *a* concentration in preference to the equation proposed by Strickland and Parsons (1972).

'n Metode vir die bepaling van totale chlorofil *a* en aktiewe chlorofil *a* in partikelstof word hier beskryf. Die pigmente is geëkstraheer in 90-persent-asetoon. Totale chlorofil *a* is bepaal deur middel van spektrofotometriese absorbansie by 665 nm. Aktiewe chlorofil *a* is geëkstraheer met heksaan deur middel van pigmentskeiding tussen waterige asetoonoplossing en heksaan soos deur Whitney en Darley (1979) beskryf. Absorbansiebepalings is met die heksaanekstraksie by 663 nm gedoen voor en ná aansuring met 5N-soutsuur. Die daling in absorbansielesing is gebruik om die hoeveelheid aktiewe chlorofil *a* te bepaal. Kalibrasiekrommes is vooraf opgestel met suiwer chlorofil-*a*-standaarde. Die krommes is toe gebruik by die berekening van die konsentrasie van chlorofil *a*. Voorkeur is aan hierdie berekening gegee bo die formule deur Strickland en Parsons (1972) aanbeveel.

The chlorophyll *a* method, described by Strickd and Parsons (1972), is widely used for determin- phytoplankton biomass in natural environments, spite the interference of inactive chlorophyll ducts which absorb at the same wavelengths chlorophyll *a*. A method has been developed to rect for the presence of phaeophytin *a* and aeophorbide *a* (Lorenzen 1967), but interference n chlorophyllide *a*, which is measured as orophyll *a*, has been reported by Jeffrey (1974). antitative thin-layer chromatography was used Jeffrey *(op. cit.)* for accurate measurements of orophyll *a* in coastal waters but, the method ng too laborious for routine use, she suggested introduction of a phase separation technique improve current methodology.

Parsons (1963) developed a method for the microtermination of chlorophyll *c*, in which interfering lorophylls and carotenoids were removed by rtitioning the pigments between aqueous acetone d hexane. Whitney and Darley (1979) reported adaptation of this method which allows more curate determination of chlorophyll *a*. The hexane perphase contains the carotenes, chlorophyll *a* d *b*, and phaeophytin *a* and *b*. The aqueous popphase contains chlorophyll *c*, some of the rotenoids and the chlorophyll degradation oducts which lack the phytol chain (chlorophyll *a* and *b*, and phaeophorbide *a* and *b*). Therefore, rtitioning with hexane removes two classes of active products from the active chlorophylls. Active chlorophyll *a* can then be determined in the hexane layer, in the presence of phaeophytin *a*, by a slight modification of the method of Lorenzen (1967).

In this study, the method of Whitney and Darley (1979) has been used to determine active chlorophyll *a*, but a new technique has been developed for measuring total chlorophyll *a*. This report deals with the techniques used to determine active and total chlorophyll *a* in the same sample, with the objective of using the results to assess the physiological state of phytoplankton communities.

METHODS

Reagents

90% (v/v) Acetone	— prepared from Analytical grade, BDH Chemicals Ltd
Hexane	— Analytical grade (67-70°C boiling range), BDH Chemicals Ltd
Anhydrous sodium sulphate	— Analytical grade, BDH Chemicals Ltd
0,0085N Sodium chloride	— prepared from Analytical grade, BDH Chemicals Ltd

5N Hydrochloric acid — prepared from Analytical grade, BDH Chemicals Ltd

Standard — 99% chlorophyll *a*, Sigma Chemical Co.

Procedure

A total of 1—2 ℓ of seawater was filtered through a 4,7-cm Whatman GF/F glass-fibre filter, precovered with 2 mℓ of 1% (w/v) $MgCO_3$. Immediately after filtering, the filter was folded, frozen in liquid nitrogen, wrapped in aluminium foil, labelled, and stored in liquid nitrogen until analysed.

The frozen filter was allowed to thaw at room temperature, then placed in a centrifuge tube with 12 mℓ of 90-per-cent acetone and, in the dark, ultrasonically agitated at 45 kHz for 20 minutes. The filter was centrifuged at 3 800 × g (15°C) for 15 minutes and approximately 10 mℓ of the supernatant drawn off for assay.

For total chlorophyll *a* determination, a 3-mℓ aliquot of the acetone extract was decanted into a 1-cm cuvette and the absorbances measured against a 90-per-cent acetone blank at 750 nm and 665 nm in a spectrophotometer. The absorbance at 750 nm was subtracted from the absorbance at 665 nm to correct for turbidity interference. The total chlorophyll *a* in 10 mℓ of extract was determined from the calibration curve and corrected by multiplying by 1,2 to give the quantity in the original 12-mℓ extract. The concentration per litre of seawater was then calculated.

In order to determine the active chlorophyll *a*, 9 mℓ of the acetone extract was first transferred to a 50-mℓ separation funnel by draining the tube straight into it. After adding 3,5 mℓ of 0,0085N sodium chloride and 13,5 mℓ of hexane and gently mixing for one minute, the phases were allowed to separate and stabilize for 3—5 minutes. The lower, aqueous phase and the interface layer were drained from the funnel, and 10 mℓ of the hexane phase was collected and dried with 0,5 g of anhydrous sodium sulphate. The absorbance of the hexane extract (in a 1-cm cuvette) was read against a hexane blank at 750 nm and 663 nm in a spectrophotometer. In order to convert the active chlorophyll *a* to phaeophytin *a*, 5 mℓ of the hexane extract was acidified with 40 μℓ of 5N hydrochloric acid and the solution well mixed. The absorbances were again read at 750 nm and 663 nm.

All absorbance readings at 663 nm were corrected for turbidity interference, measured at 750 nm, and the difference in absorbance readings between non-acidified and acidified solutions was calculate Active chlorophyll *a* was determined from th calibration curve and multiplied by 1,33 to giv the quantity in the original extract. The factor 1,33 was applied because only 9 mℓ of the origin 12 mℓ of acetone extract was used in the partitio step. The concentration of active chlorophyll per litre of seawater was then calculated.

Standard solutions were prepared with 5, 10, 1 and 20 μg chlorophyll *a* • 10 ℓ^{-1} 90-per-cen acetone. Absorbances were measured at 750 n and 665 nm and a standard curve was prepare for determining total chlorophyll *a* concentratio The standard solutions were then extracted int hexane and the absorbances measured at 750 n and 663 nm before and after acidification with 5 hydrochloric acid. A standard curve relating th decrease in absorbance to chlorophyll *a* concentra tion was prepared for determining the concentratio of active chlorophyll *a*.

RESULTS AND DISCUSSION

Strickland and Parsons (1972) recommende that samples for chlorophyll analysis should b extracted immediately after filtering, but this wa found to be impractical on the small researc vessel used for sample collection. Filters wer stored at -20°C in initial studies, but further test revealed that the storage of filters in liquid nitroge gave the highest results. The extraction of chloro phyll can be aided by initially grinding the phyto plankton cells in the dark for 20h (Strickland an Parsons *op. cit.*). However, the recommendatio of SCOR/Unesco Working Group 17 (1966) tha ultrasonic treatment be employed was adopted and this technique reduced the time required fo extracting pigments to 20 minutes.

The calibration curves for determining tota and active chlorophyll *a* are illustrated in Figur 1. A spectral scan of the standard solution indicate that, in acetone, the pigment absorbed maximall in the red region of the visible spectrum at 665 nm but at 663 nm when the pigment was extracte into hexane. The acidification step used in thi method was similar to that used by Lorenze (1967) with a reduction in absorbance bein recorded when chlorophyll *a* was converted t the phaeophytin form. The phaeo-forms of chloro phyll *a* do not show a reduction in absorbanc when treated with acid, and this fact enable chlorophyll *a* to be determined in samples con taining phaeopigments.

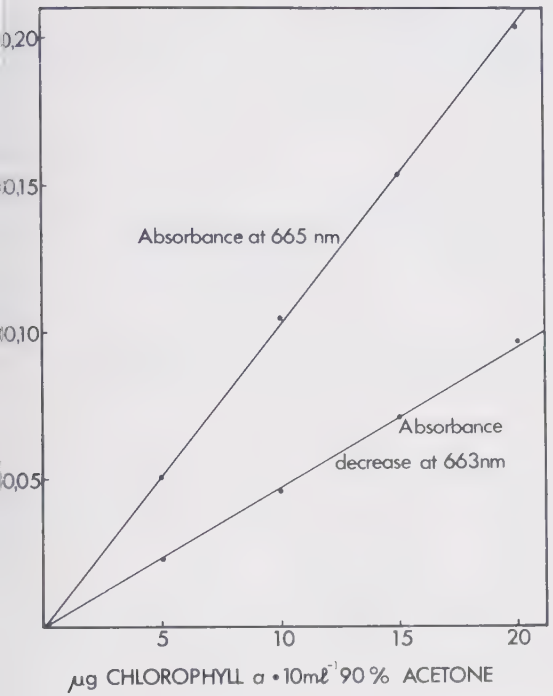

Fig. 1: Calibration curves for total and active chlorophyll *a* determination

Trichromatic equations were recommended by ickland and Parsons (1972) and SCOR/Unesco rking Group 17 (1966) for calculating chloro-yll *a* concentrations. However, it is felt that, h the availability of pure chlorophyll *a*, more urate estimates can be made by preparing cali-tion curves, and this opinion is held by others S. Yentsch, Bigelow Laboratory for Ocean iences, U.S.A., personal communication). Under

Table I: Accuracy of the chlorophyll *a* methods

Assay	Absorbance	Taken (µg•10mℓ⁻¹)	Found (µg•10mℓ⁻¹)	Error (%)
tal lorophyll *a*	0,051	5,00	5,00	0
	0,105	10,00	10,25	2,5
	0,154	15,00	15,00	0
	0,204	20,00	19,85	0,7
ctive lorophyll *a*	0,023	5,00	4,87	2,6
	0,046	10,00	9,68	3,2
	0,071	15,00	15,00	0
	0,097	20,00	20,46	2,3

Table II: Chlorophyll *a* concentrations, Robben Island (12 km north-west of Cape Town), October 1979

Station	Depth (m)	Total chlorophyll *a* (µg•ℓ⁻¹)	Active chlorophyll *a* (µg•ℓ⁻¹)
1	0	8,97	3,14
	2,5	8,84	4,57
	5,5	3,36	2,29
	8,5	3,36	2,51
2	0	8,09	4,29
	1,5	9,34	4,29
	3,0	9,45	5,72
	5,5	9,22	5,14
	11,0	8,47	4,86

the conditions described, the methods can be expected to be accurate within ±3 per cent. This figure was obtained by plotting the results and comparing the amount of chlorophyll actually present with that indicated by the plot. The percentage errors are shown in Table I.

Some chlorophyll *a* determinations from field samples are presented in Table II. The results show that all the active chlorophyll *a* concentrations were lower than total chlorophyll *a*. This was expected, because inactive forms of the pigment would be produced by rapidly growing phytoplankton communities in eutrophic waters (Whitney and Darley 1979). In further investigations, it is proposed to assess the value of the active chlorophyll *a*: total chlorophyll *a* ratio as an indicator of the physiological response of phytoplankton to changes in the environment.

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ANALYSIS OF ADENOSINE TRIPHOSPHATE IN PARTICULATE MATTER

R. G. BARLOW

A simple method is described for determining ATP making use of firefly luciferin-luciferase and a scintillation counter. The procedure may be used to determine ATP in particulate matter in the range 2×10^{-7} to 10×10^{-10} mole. It was found that samples preserved in liquid nitrogen yielded the highest recoveries of ATP.

'n Eenvoudige metode word beskryf vir die bepaling van ATP met vuurvlieg-lusiferien-lusiferase en 'n flitsteller. Die metode kan gebruik word vir die bepaling van ATP in partikelstof in die bestek 2×10^{-7} tot 10×10^{-10} grammolekuul. Daar is bevind dat monsters wat in vloeibare stikstof bewaar was 'n hoër opbrengs van ATP getoon het.

In studies of phytoplankton production and food-hain dynamics, a measure of the living biomass f particulate matter suspended in the sea is often esired. Such measurements can be made micro-copically, but this is time-consuming and it is asier and quicker to measure some chemical onstituent that is present in all living cells though ot associated with detrital material. Adenosine iphosphate (ATP) is a cellular constituent that ulfils these requirements.

ATP measurements have been used by the author o quantify living biomass in physiological studies f phytoplankton communities. Holm-Hansen and ooth (1966) developed the ATP method, but the echniques reported by Strickland and Parsons 972) form the basis of the method used here.

The method involves the oxidation of a substrate, uciferin, by an enzyme, luciferase, and the emission f light in the process. ATP is required as an nergy source in the reaction and the quantity of uminescence is proportional to the amount of TP present. Strickland and Parsons (1972) escribed a laboratory-built apparatus that easured the emitted light but, in this study, use was made of a commercial liquid scintillation ounter to measure the luminescence. Other daptations of the method for application to local conditions were also made and are reported.

METHODS

Reagents

Tris buffer	—	0,02M; pH7,75; prepared from Analar Tris (hydroxymethyl) methylamine, BDH Chemicals Ltd
Enzyme mixture	—	Firefly lantern extract, FLE-50, Sigma Chemical Co.
Standard	—	Sigma grade disodium adenosine triphosphate, Sigma Chemical Co.

Procedure

Half a litre of seawater was filtered through a 4,7-cm Whatman GF/F glass-fibre filter. Immediately after filtering, the filter was folded, frozen in liquid nitrogen, wrapped in aluminium foil, labelled, and stored in liquid nitrogen until analysed.

An amount of 5 mℓ of boiling Tris buffer was pipetted into a 150-mℓ beaker (covered with a watch glass) on a boiling water bath, and ATP was extracted by placing the frozen filter in this boiling solution for five minutes. The extract was transferred to a clean dry tube and the filter extracted with a further 3 mℓ of boiling buffer for two minutes. The extracts were combined, cooled, made up to 8 mℓ with distilled water, frozen in liquid nitrogen, and stored at -20°C until analysed.

The enzyme mixture was prepared by extracting 50 mg of firefly lantern extract with 5 mℓ of Tris buffer for 2—3 hours at room temperature. The mixture was centrifuged at 300—400 × g (room temperature) for two minutes and the supernatant decanted into a clean dry tube. This extract was allowed to stand for a further hour before diluting to 10 mℓ with Tris buffer. The diluted preparation was used within three hours.

Standards were freshly prepared for each analysis

with 0,1; 0,05; 0,01; 0,005; 0,0005 μg ATP • mℓ$^{-1}$ Tris buffer, including a blank (1 mℓ Tris buffer) for background counts. Aliquots (1 mℓ) of blanks, standards and sample extracts were added to a series of 8-mℓ glass scintillation vials in counting racks suitable for a Packard Prias liquid scintillation counter. An empty vial was placed in the first position of each rack and the counter set in the single-count automatic mode, out of coincidence, with counting windows appropriately set for optimum counting efficiency. The counter was programmed to count each vial for six seconds.

As soon as the printout of counts from the empty vial began, 0,2 mℓ of enzyme was injected into the next vial through a small hole drilled in the cap. The contents of the vial were swirled briefly and the vial was inserted into its appropriate position in the counting rack. Counting commenced 27 seconds after the addition of the enzyme. The count was an integral measurement of the area under the luminescent decay curve between 27 and 33 seconds after the start of the reaction. Subsequent samples were reacted and counted at a similar time interval. Duplicate analyses on the extract from each filter were performed.

The background count of the blank determination was subtracted from the counts of all samples and standards to obtain net counts. Net counts and standard concentrations were transformed to logarithmic functions, and equations of the form $\ln y = a + b \ln x$, relating counts to standards, were formulated for each set of standards. The concentration of ATP in each sample was calculated from either of these equations.

RESULTS AND DISCUSSION

ATP must be extracted immediately after filtering to prevent the degradation of ATP, but extraction at sea was found to be totally impractical on the small research vessel used for collection of samples. Therefore, samples were frozen in liquid nitrogen immediately after filtering and held in this liquid at −190°C until extracted. The frozen filters were then extracted in boiling buffer in a shore-based laboratory. The results presented in Table I show that frozen samples gave a higher ATP yield than freshly extracted samples.

In the original method (Holm-Hansen and Booth 1966), the amount of emitted light was determined by tracing the decay curves with a pen recorder and then measuring the area under the curves. The utilization of a liquid scintillation counter

Table I: ATP concentrations in particulate matter fro
20 ℓ of surface water collected at Sea Point,
August 1977

Sample number	ATP (μg•ℓ$^{-1}$)	
	Freshly extracted	Frozen before extractio
1	0,199	
2	0,103	
3	0,122	
4	0,127	
5	0,166	
6	0,100	
7		0,235
8		0,219
9		0,281
10		0,227
11		0,268
12		0,180

improved the procedure by recording the area under the decay curves as an integral count of the emitted luminescence. Furthermore, the pen recording technique involved adjustment of a range selector sensitivity switch each time a sample was assayed. With the scintillation counter, counting windows were present to optimize counts within the range of the standards.

It was necessary to calculate two standard equations for each set of standards. The standard concentration range from 0,0005 to 0,1 μg ATP mℓ$^{-1}$ Tris buffer was found to be too wide to b

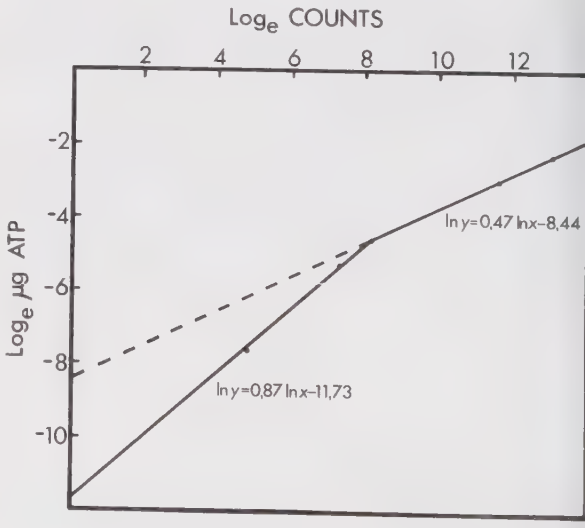

Fig. 1: Standard equations for ATP determination

equately expressed by one equation and an lection point at a concentration of 0,01 μg TP • mℓ$^{-1}$ buffer was estimated. An equation vering the concentration range from 0,0005 to 1 μg ATP • mℓ$^{-1}$ buffer was therefore formulated d another for the range from 0,01 to 0,1 μg TP • mℓ$^{-1}$ buffer. Figure 1 illustrates these standard uations.

Measurement of ATP in the ocean provides timates of total living biomass, which includes ytoplankton, zooplankton and bacteria. Therere, in surface waters, ATP needs to be related other parameters, such as chlorophyll *a*, when is used in phytoplankton studies. Probably the ost useful application of ATP measurements would be in estimating bacterial biomass in deep water, where there would be no contribution from living plankton.

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MODIFIED COLLAPSIBLE OPENING AND CLOSING MIDWATER TRAWLS (RMT-8 AND RMT-2)

A. A. ROBERTSON, D. G. W. ALEXANDER and D. G. M. MILLER

Space restrictions on a vessel not designed for fisheries research necessitated modifications to the afterdeck to permit aimed fishing for krill. A standard (I.O.S.) RMT-8 system was modified to reduce its size during shooting and recovery. Modifications included the construction of an electromechanically operated net-release system. A smaller 2-m² net (RMT-2) and release mechanism were also built to reduce handling effort.

As gevolg van die beperkte ruimte op 'n vaartuig wat nie vir visserynavorsing ontwerp is nie, moes daar aan die agterdek wysigings aangebring word om gerigte krilvangs te kan doen. 'n Standaard-RMT-8-stelsel van die I.O.S. is gewysig ten einde die omvang daarvan tydens uitwerp en inhaal te verminder. Een van die wysigings was die konstruksie van 'n elektromeganiese netlosser. 'n Kleiner 2-m² net (RMT-2) en lossermeganisme is ook vervaardig om hantering te vergemaklik.

After the Sea Fisheries Institute's first acoustic urvey of Antarctic krill *Euphausia superba* Dana n 1978 (Cram *et al.* in press), a programme was stablished to prepare for the First International iomass Experiment (FIBEX) in 1981. The techiques evolved drew from experience gained during he 1978 cruise and were centred mainly on acoustic ethods of stock size estimation. Identification of coustic targets was to be made with the aid of a odified Institute of Oceanographic Sciences I.O.S.) rectangular midwater trawl, RMT-8 (Clarke 969). This decision was based on the results of e system developed during 1978 on the S.A.S. *rotea* (Robertson 1979), and on the recommendaon that the RMT-8 be used during FIBEX (Anon. 979).

However, not all vessels available for work in he Southern Ocean are suitable for the deployment f large plankton nets such as the RMT-8. Furtherore, results of the 1978 survey indicated that coustic target identification could be considerably hanced by directed fishing on specific shoals, warms or layers. As a result, the Sea Fisheries stitute developed a collapsible RMT fitted with n electromechanical opening and closing device. Both net and closing device were designed with he aim of facilitating net deployment from ships ot suitable for trawling work. In addition, the eed to experiment with smaller, more manageable ets was recognized.

The developed gear was tested during three ruises made to the South Atlantic in 1980/81 board the supply and relief ship *S.A. Agulhas*. Two systems are described, an electromechanically perated opening/closing RMT-8 fitted with a et-sonde for fishing at discrete depths, and a maller (2 m²) opening and closing RMT-2.

STANDARD NET (RMT-8)

Arrangement of gear

Certain problems were encountered in fitting out the *S.A. Agulhas* for stern trawling.

(i) There were no towing facilities on the stern.
(ii) The after working area was completely covered by a helicopter deck, and the distance between the curtain plate of this deck and the gunwale of the poop deck (2 300 mm) posed serious difficulties in the deployment of large RMT nets.
(iii) There was no gantry or davit on the working deck for lifting large RMT nets clear of the sea surface.

These problems were largely overcome by adopting the methods used on *Protea* (Robertson 1979). The net was triced during shooting and recovery by means of an "A" frame mounted on the helicopter deck. A variety of equipment was fitted to the vessel, the main components being the "A" frame and a slipring winch. The general arrangement of equipment is shown in Figure 1 and Table I gives details of the winches used.

Table I: Details of slipring winches

	RMT-8 winch	RMT-2 winch
Drive	Electro-hydraulic	Electro-hydraulic
Cable	7 core, 13 mm diameter	4 core, 9,5 mm diameter
Drum capacity	500 m	250 m
Pull	2 500 kg at 1m·s^{-1}	1 500 kg at 1m·s^{-1}

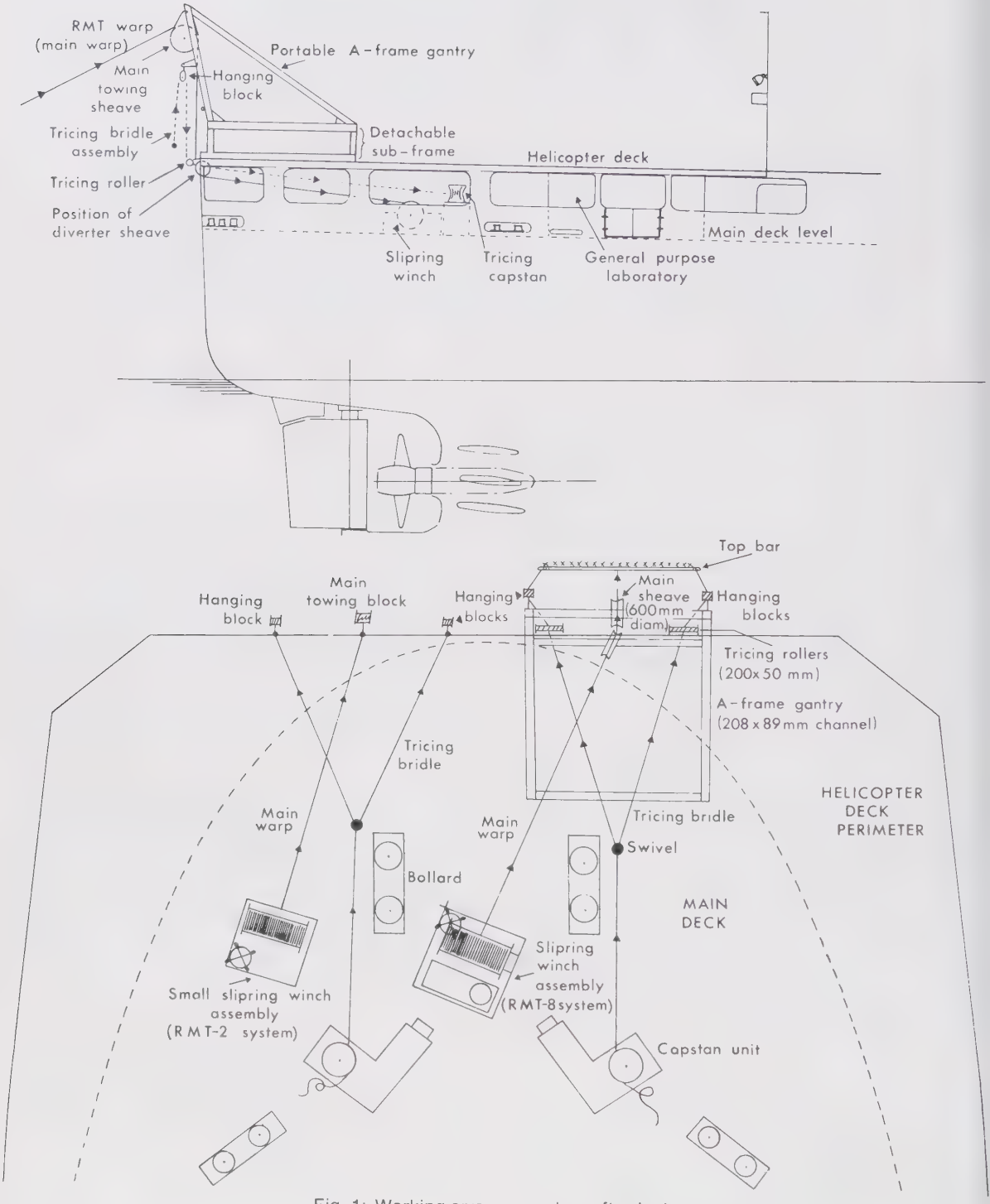

Fig. 1: Working arrangement on afterdeck

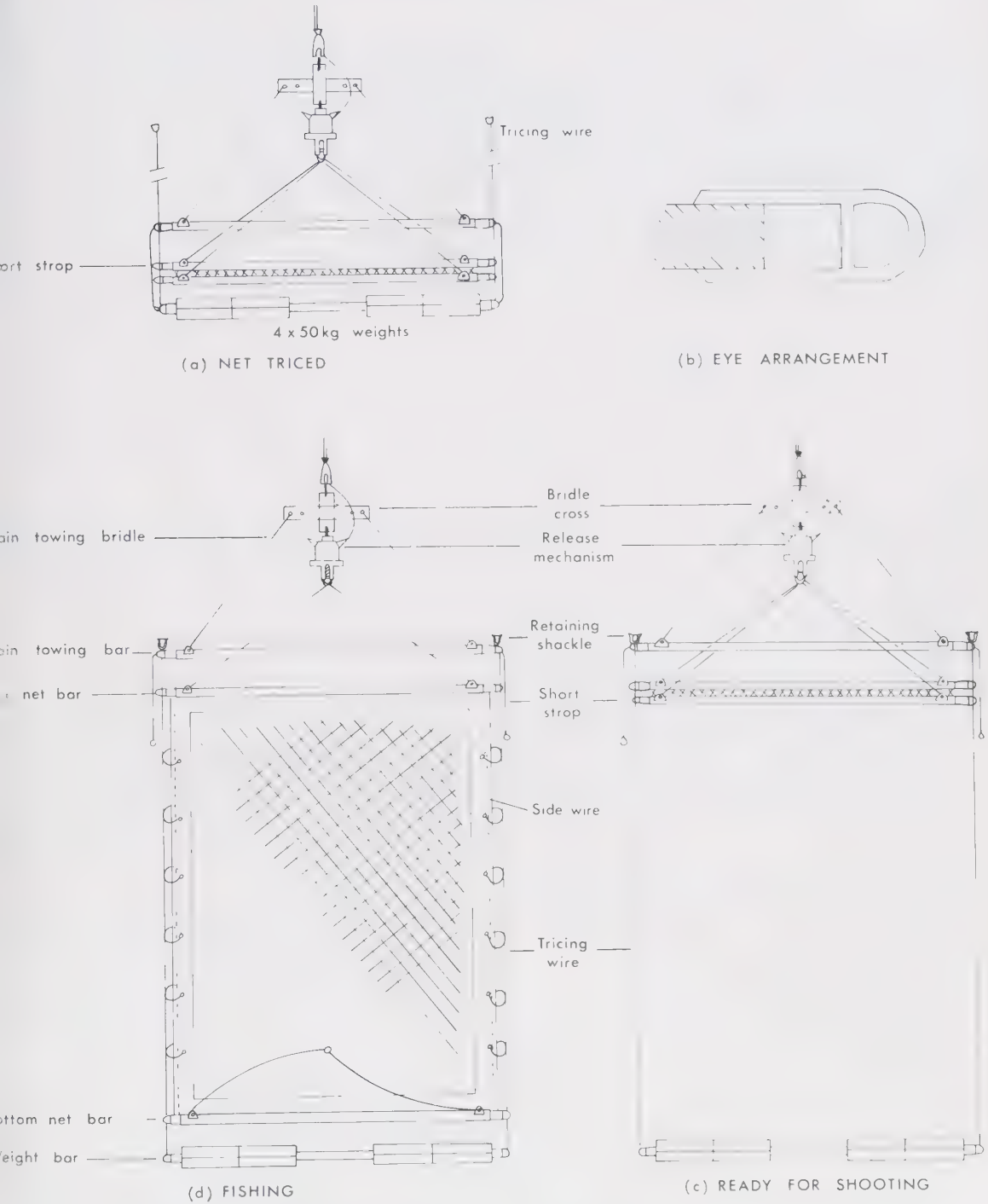

Fig. 2: General arrangement of RMT-8 (not to scale)

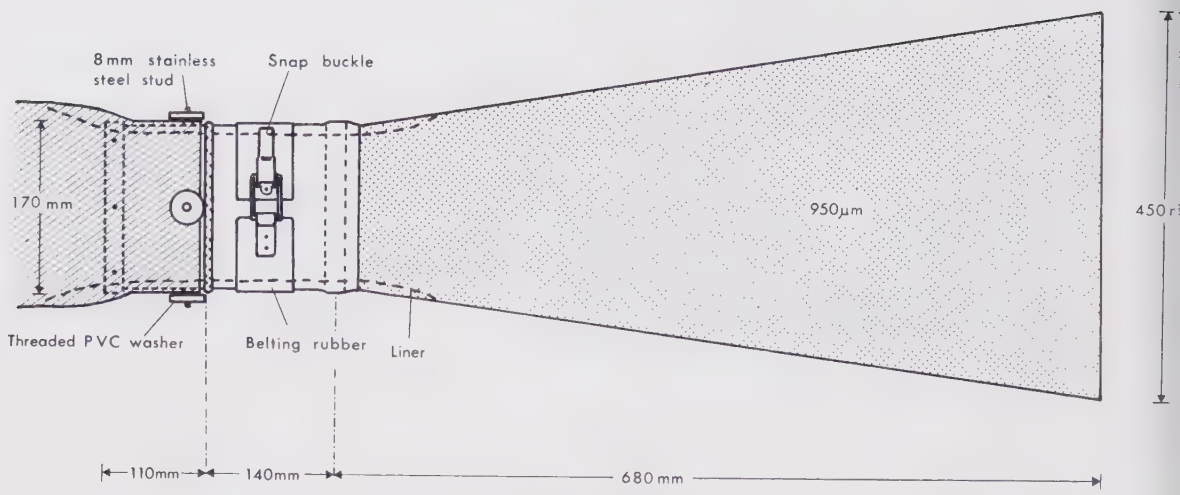

Fig. 3: Codend arrangement

The net

The modifications made to Clarke's (1969) design are outlined below.

(i) The eyebolts on the towing and net bars were replaced by the double-eye arrangement shown in Figure 2, detail (b). The inner eyes were used for securing the sidewires between the two net bars. The tricing wires were shackled to the outer end of the weight bar and led through the outer eyes of the towing and net bars. The upper ends were held in position by shackles to which ropes could be attached for tricing the net.

(ii) The bridle cross had two sets of holes, the outer to hold the towing bridles, and the inner to secure a net-sonde transducer kite (Fig. 2).

(iii) A modified codend assembly based on that described by Baker *et al.* (1973) was constructed (Fig. 3). The system was specifically designed for rapid and easy removal at the sub-zero temperatures in which the net was to be used. It comprised an aluminium tube firmly secured to the end of the net, a quick-release clamping band and the codend bag. The bag was made of monofilament nylon netting sufficiently rigid to obviate collapsing of the codend and subsequent damage to the catch (Clarke 1969). A liner of 500-μm nylon netting was sewn into the end of the net. To facilitate the retrieval of the codend assembly a Becket rope was attached to the net immediately above the aluminium tube and secured to the towing bar.

Release mechanism

An acoustically activated release mechanism successful to 5 000 m has been in general use for some time (Baker *et al.* 1973). As a system was required for shallow work on krill (± 200 m), an electromechanical release mechanism was considered adequate and, because of cost, was preferable to the acoustic system. The mechanism developed adheres to the mechanical principles of the acoustic system.

The mechanism is activated by a coded electrical signal transmitted through one of the towing-warp conductors to an electric motor. The motor drives a rotating cam which in turn depresses a lever to free the bottom net-bar bridle thereby opening the net. A second signal closes the net by repeating the above sequence and releasing the top net-bar bridle. A schematic representation of the system is given in Figure 4.

The components for operating the relevant levers are housed in a machined, cylindrical, phosphor-bronze casing designed for depths down to 200 m (Fig. 5). The cover plate and lever housing are also machined from phosphor-bronze. Stainless steel is used for all release levers. The casing is sealed by means of conventional rubber "O" rings. Envirocon bulkhead socket connectors are fitted

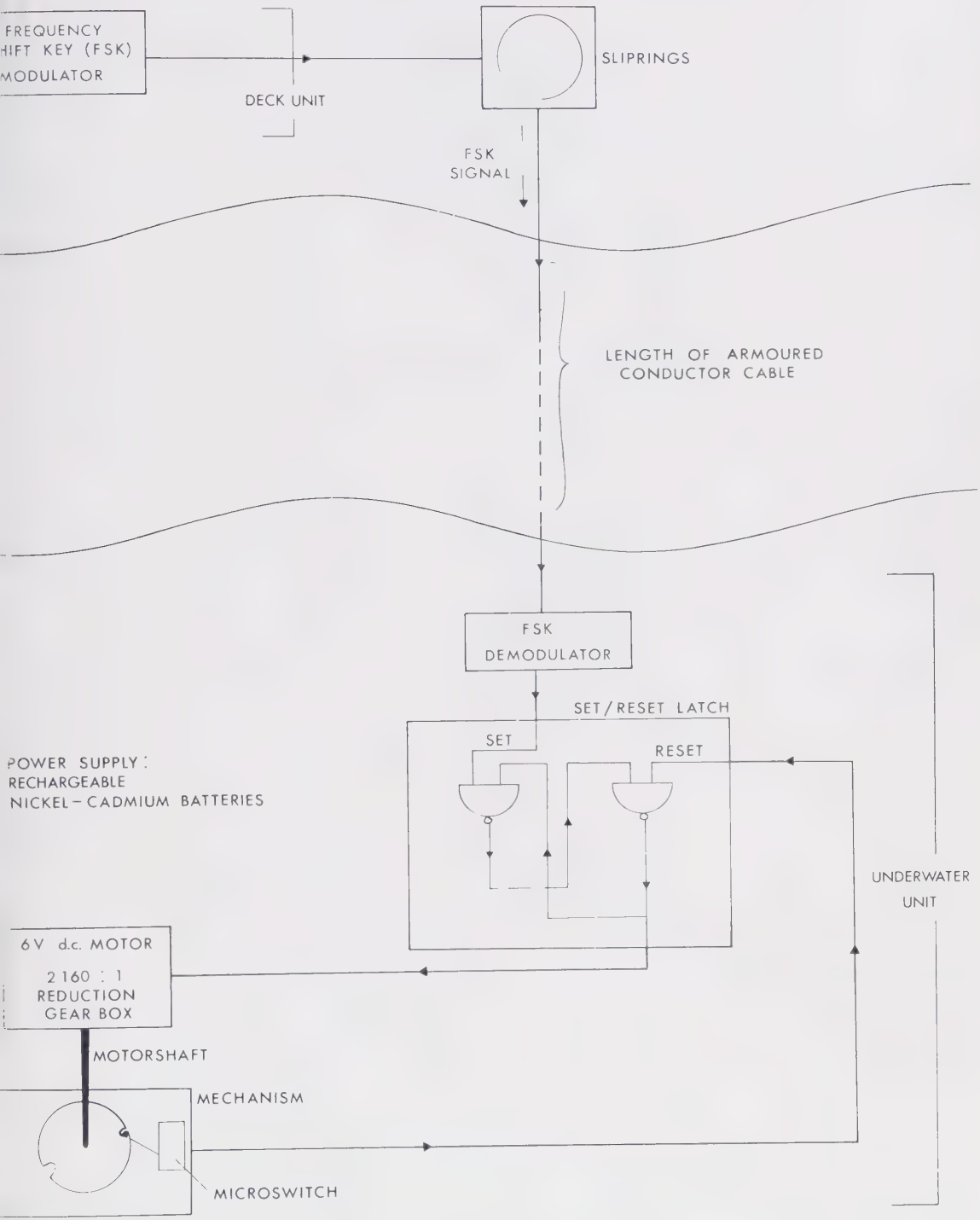

Fig. 4: Block diagram of the operation of the opening and closing mechanism

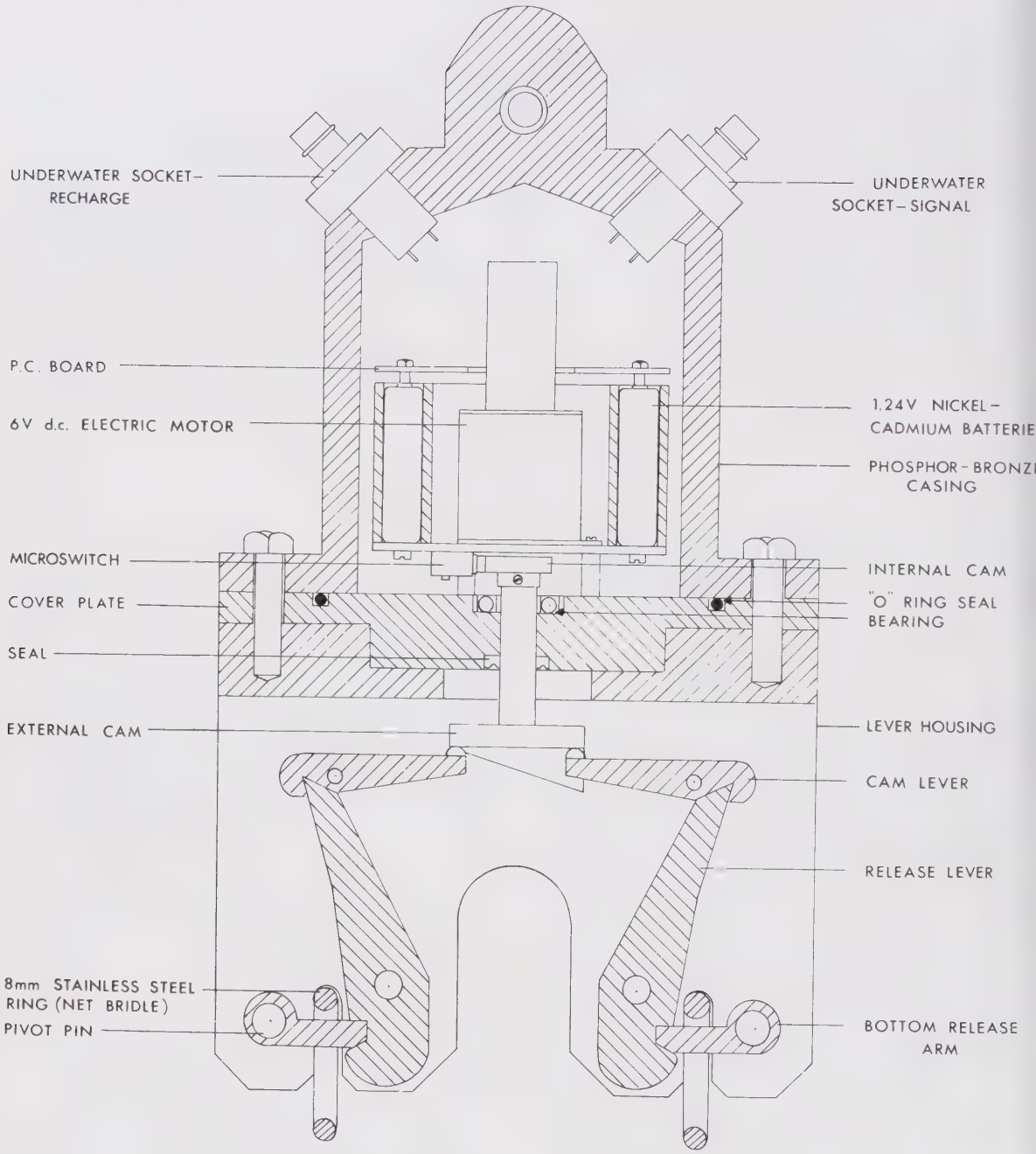

Fig. 5: Release mechanism

on the top of the release-motor housing, one for connecting the signal conductor, the other for recharging the batteries which supply power to the release motor.

A 6 V d.c. motor (ESCAP 23D 212216PI) is used to drive the bridle release cam. The drive shaft is connected to a 2 160:1 reduction gearbox to give the required speed reduction and torque

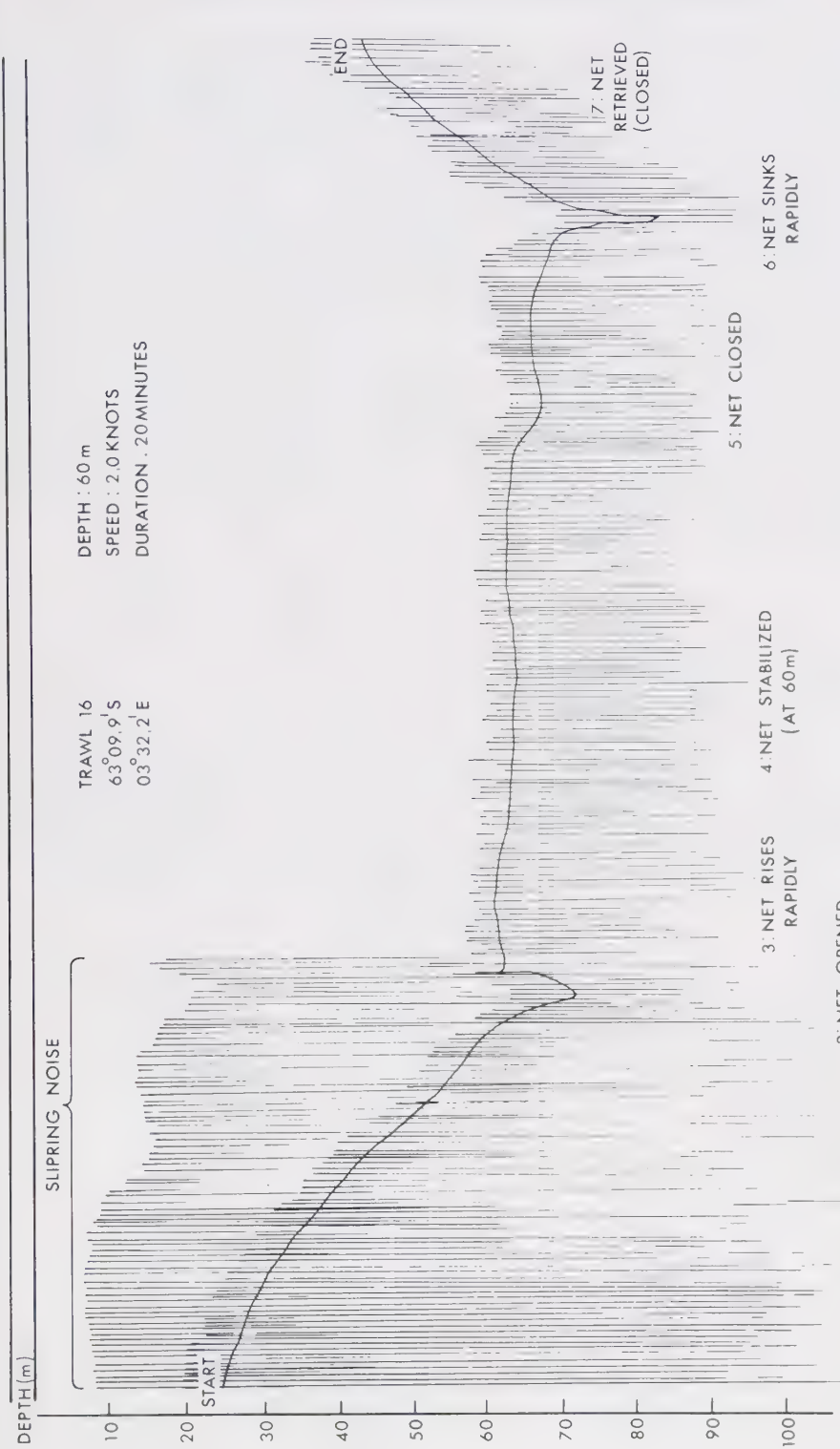

Fig. 6: Schematic net-sonde trace of a fishing operation

amplification. Power supply is by means of 12 nickel-cadmium batteries (1,24 V) mounted in a circle around the motor.

The release gear is primed by inserting the bridle rings of the top and bottom net bars into the rear and front jaws of the lever housing. The bottom release arms are swung through the bridle rings and locked into position on the release levers, the latter being manually operated by a working system acting on the cam lever.

The initial electrical signal activates a relay to supply power to the d.c. motor, which then drives the external cam shaft. An internal cam, mounted on the same shaft, operates a two-way microswitch to cut the motor power supply once the shaft has rotated through 180°. The 180° movement of the external cam activates the cam- and release-levers allowing the first (lower) net-bar bridle to drop away. A second signal repeats the sequence to release the upper net bar, thus closing the net.

Net-sonde

The depth of the net is monitored in real time by means of a 50-kHz echo-sounder transducer mounted on a kite attached to the bridle cross. The transducer faces upwards and is kept horizontal by the flow of water. The transducer signal is transmitted to a chart recorder on deck via four (2 + 2) of the seven conductors in the trawl warp. A schematic representation of a typical recorder trace is presented in Figure 6.

Fishing operations

The net was triced and, with the short strops clipped into position, manhandled over the stern (Fig. 2a). The net-bar bridles were inserted into the release gear and the mechanism cocked. The effect of the weight bar was then taken up by hauling on the tricing wires by means of the port-side mooring capstan (Fig. 1).

On unclipping the short strops, the tricing wire was slowly paid out to allow the weight bar to fall to the full extent of the side wires supporting the net (Fig. 2c). The tricing bridle was then disconnected and the main warp let out until the net was approximately 10 m below the required fishing depth. Increased drag on opening the net tended to cause it to rise to the required fishing depth. This change could be observed on the net-sonde trace, thereby giving a useful indication of successful net release. Conversely, net depth could be seen to increase on net closure.

Retrieval procedure was the reverse of shootin the net being triced closed and the weight b secured by the short strops. The codend w brought inboard by means of the Becket rop Once the catch had been removed the net w made ready for the next haul. The small ga between the decks made manhandling of the n over the stern a difficult operation and, in practic the net frame was not brought inboard unle repairs were necessary. The net frame was firml secured to the "A" frame with strops and snatc links, the latter for quick release and deployment

Time taken for shooting and retrieval varie between two and six minutes depending on weathe conditions. Towing speeds were between 2 an 2,5 knots with the ship steaming into the wind an sea. Once the net was in the water, the ship's hea was allowed to fall off until the wind and sea wer on the beam.

SMALLER NET (RMT-2)

Arrangement of gear

The RMT-8 system proved to be workable from *S.A. Agulhas* in spite of the very restricted working area. However, the communication problem resul ting from having to use two decks for net de ployment, plus the fact that the "A" frame had to be removed entirely when the vessel was carrying helicopters, created the need for a smaller net. The following requirements were used as a basis for the design:

(i) small and lightweight construction for ease of handling;
(ii) capacity for opening and closing operation;
(iii) real-time monitoring of depth;
(iv) shooting and retrieval to be carried out without the use of a gantry;
(v) mouth area to be large enough for representative, qualitative sampling of *Euphausia superba*.

The arrangement of equipment on the after deck is shown in Figure 1, and details of the slipring winch are given in Table I.

The net

The selection of the net size was not based on any knowledge of the avoidance capability of

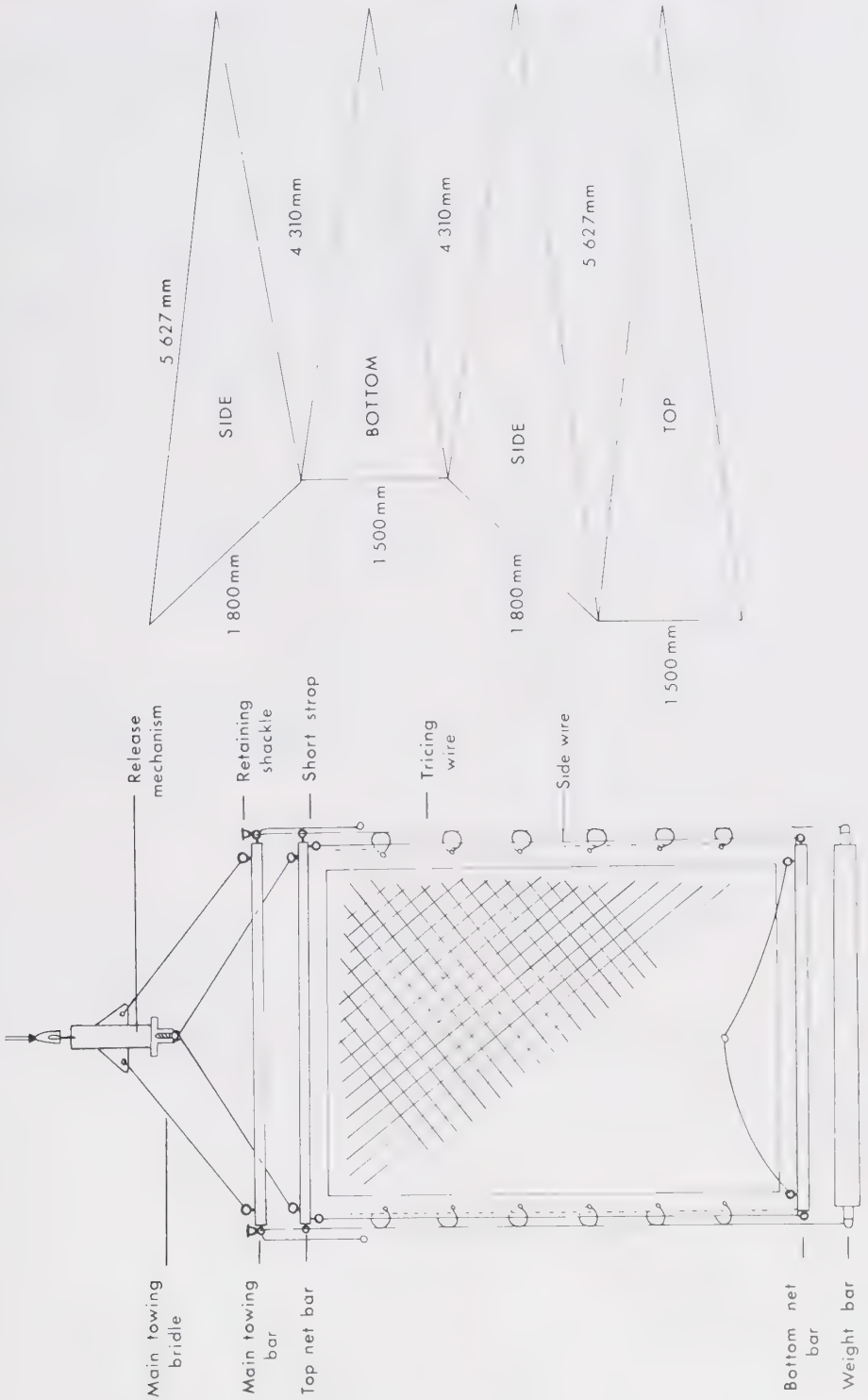

Fig. 7: General arrangement of RMT-2 (not to scale)

krill, but more on the maximum dimensions that could be handled without the use of an "A" frame. The size eventually decided upon was 1 500 mm wide by 1 800 mm deep. This gave the net an effective mouth area of approximately 2 m^2 when fishing (Fig. 7).

The net was made of 100-per-cent polyester netting with a mesh size of 4,5 mm. Panels were cut to provide maximum porosity during fishing. Porosity was calculated to be in the region of 55 per cent. The netting material was dyed black to reduce avoidance of the net by more mobile organisms (Le Brasseur *et al.* 1967).

The general arrangement of the bridles, net bars and tricing wires was similar to that of the RMT-8, but with a number of features to lighten construction.

(i) Stainless steel was used for all net bars and towing bar, bridles, wires and connectors.
(ii) The net bars were differently constructed in that threaded eyebolts were used for the attachment of bridles and to accommodate the tricing and side wires.
(iii) To reduce the possibility of damage to the netting, all wire splices were dressed with heat-shrunk tubing. For the same reason, no shackles were employed and Quicklinks were used for all connections.
(iv) To reduce the possibility of damage by the depressor weights or their securing devices, a lead-filled pipe was used as a weight bar. Total mass was approximately 50 kg.

The complete net assembly with the weight bar removed weighed ± 14 kg.

Further details of the net are given in Table II.

Table II: RMT-2 rigging detail

Item	Length (mm)	Diameter (mm)	Wall thickness (mm)	Remarks
Towing bar	1 600	25	3,4	Schedule 40
Net bars	1 600	25	2,8	Schedule 10
Weight bar	1 500	75	8,0	Galvanized s
Towing bridle	920	5	—	
Top-bar bridle	880	5	—	
Bottom-bar bridle	820	5	—	Constructio
Side wires	1 700	5	—	7 × 19: 12/(
Tricing wires	2 300	5	—	
Codend tube	150	100	6	Polypropyle

Release mechanism

Initially, the RMT-8 release mechanism was used with the small net. However, it was evident that many aspects of the mechanism's design could be improved, and a lighter mechanism was constructed. Differences from the prototype are outlined below.

(i) Power to the motor is supplied via the conductor cable.
(ii) The unit houses a depth sensor with digital display on deck.
(iii) The casing is constructed of stainless steel tubing and plate.
(iv) The bridle cross takes the form of two eyeplates welded to the tubular section of the casing.
(v) The mechanism weighs only 20 per cent as much as its prototype.

Net-sonde

Hauls made with the modified release mechanis were monitored by the depth sensor, no ne sonde being employed.

Fishing operation

The shooting and recovery procedure is simil to that of the larger net. However, the net can b handled by three men as opposed to the fi required with the RMT-8.

DISCUSSION

The equipment and procedure described facil tated rapid and effective deployment of an openi and closing RMT from a vessel not designed f trawling work. No major structural changes to th vessel were necessary, and it is envisaged tha adaptations of the current ideas could be utilize for similar vessels of opportunity that are n designed for towing nets.

The operation of both systems, particularly th RMT-8, involves a number of people in variou compartments on the vessel. Successful launchin fishing and retrieval depends very much on th degree of communication between them. Whe handling operations are carried out on two differe decks, as with the RMT-8, good communicatio between decks is imperative if accidents are to b avoided. During fishing operations, the winc operator must have easy contact with the bridg and acoustics laboratory so that changes in fishi strategy, which can be fairly frequent whe attempting to sample acoustic targets, can b

ted with the minimum of delay.
date, the RMT-8 has been used successfully
shing for krill. However, a detailed study of
MT-2 performance is necessary to determine
accurately the weight of depressor needed
aintain a mouth angle of 45° at speeds of 2 —
nots. Roe *et al.* (1980) have shown that, at
nal towing speeds, mouth angle (and therefore
th area) is sensitive to changes in speed. During
l trials, weight bars of 50 kg and 100 kg were
, but little difference in mouth angle was
rved. These rather crude observations were
e visually, from an inflatable boat running
e to the net which was being fished close to
surface. More detailed clinometer tests are
ssary to establish the effect of the weight bar
greater precision.
y far the easiest way to shoot an RMT is over
stern of the vessel via either a large crane or
n ramp. The methods described above should
seen as an attempt to make the best of the
ation when faced with a vessel wholly unsuited
the type of operation. It should also be noted
the samplers described were developed with
nited purpose in mind: that is to qualitatively
ple, and thus classify, acoustic targets, particu-
Euphausia superba. Work is therefore carried
fairly close to the surface, generally in the
er 200 m, making the use of conductor cables
electromechanical devices both practicable
relatively inexpensive.

ACKNOWLEDGEMENTS

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ontinual encouragement and guidance. The systems described required considerable input on the part of staff in the mechanical, electronic and marine workshop groups of the Sea Fisheries Institute, and their efforts ensured the readiness of the equipment for FIBEX. Funding for the development of this equipment was provided by the Council for Scientific and Industrial Research via the South African National Committee for Oceanographic Research and is gratefully acknowledged.

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REMOTELY CONTROLLED HYDROPHONE SYSTEM FOR CALIBRATION OF HULL-MOUNTED ECHO-SOUNDER TRANSDUCERS

I. HAMPTON, P. DE BRUYN, W. I. R. LEONARD and M. J. PATERSON

An electromechanical system to facilitate precise positioning of a calibration hydrophone on the axis of a hull-mounted echo-sounder transducer is described. The hydrophone is attached to a rigid frame held onto the hull by magnets, and its position is adjusted by two remotely controlled stepping motors. The system has been used to calibrate a 120-kHz hull-mounted transducer. It was found to give sufficient positional control to keep misalignment errors to below 2,5 per cent. The system also facilitates the measurement of beam patterns in a plane parallel to the active face of the transducer.

'n Beskrywing word gegee van 'n elektromagnetiese stelsel vir die presiese plasing van 'n kalibreerhidrofoon op die as van 'n rompgemonteerde eggoloodoordraer. Die hidrofoon word vasgeheg aan 'n stewige raam wat met magnete aan die romp bevestig word, en sy posisie word reggestel deur twee afstandsbeheerde stapmotore. Die stelsel is reeds gebruik vir die kalibreer van 'n rompgemonteerde oordraer van 120 kHz. Daar is bevind dat dit genoegsame standkontrole bied om wanrigtingsfoute benede 2,5 persent te hou. Ook vergemaklik die stelsel die meting van die bundelpatrone in 'n vlak parallel met die aktiewe vlak van die oordraer.

order to make acoustic estimates of fish dance, it is necessary to calibrate an echo- der to an accuracy well within that desired of timate. The usual way to calibrate an echo- der is to measure the sound pressure level cted from the transducer and the sensitivity transducer to received sound waves at the ance frequency. The bandpass characteristics receiving system should also be determined. measurements are made with a hydrophone own receiving and transmitting sensitivity ed on the acoustic axis of the transducer at a distance well beyond the near-field zone Urick 1967). To complete the calibration the pattern (directivity) of the transducer should e determined, preferably by measuring the itted sound pressure or receiving sensitivity unction of displacement off axis in a plane el to the active face of the transducer.

en using this method to calibrate transducers ted in a ship's hull, it is difficult to achieve ate results because of the need for precise oning and the difficulty of making fine posi- adjustments underwater where the hydro- e is out of sight. For practical reasons (e.g. ity of the mounting arrangement, limited of water below the keel) the hydrophone o be mounted as close to the transducer as near-field will allow (typically 2—3 m for sonic transducers of the type commonly used eries acoustics). However, this close mounting ituates the positioning problem because, at range, the sound intensity falls off very sharply distance off axis, particularly for narrow- transducers. This fall-off is illustrated in e 1, where the total calibration error is shown

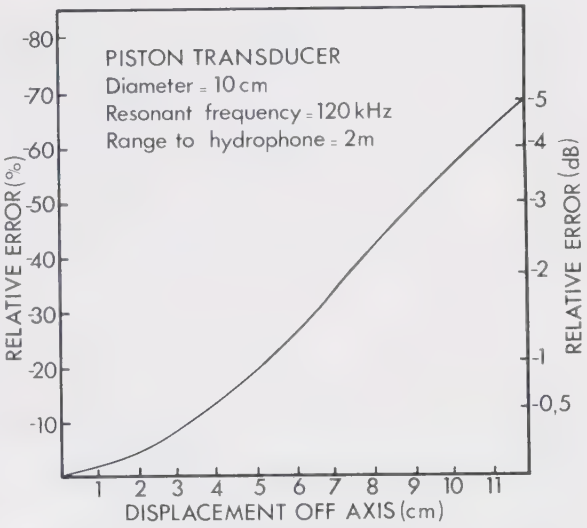

Fig. 1: Total calibration error as a function of hydrophone displacement off axis

as a function of displacement off axis for a 120-kHz, 10-cm diameter piston transducer at a range of 2 m. (This type of transducer is widely used in fisheries research for quantitative acoustic studies.) In obtaining Figure 1, the theoretical beam function

$$b(\theta) = \left[\frac{2J_1\left(\frac{\pi D}{\lambda} \sin\theta\right)}{\frac{\pi D}{\lambda} \sin\theta} \right]^2$$

has been used, where $b\ (\theta)$ is the normalized

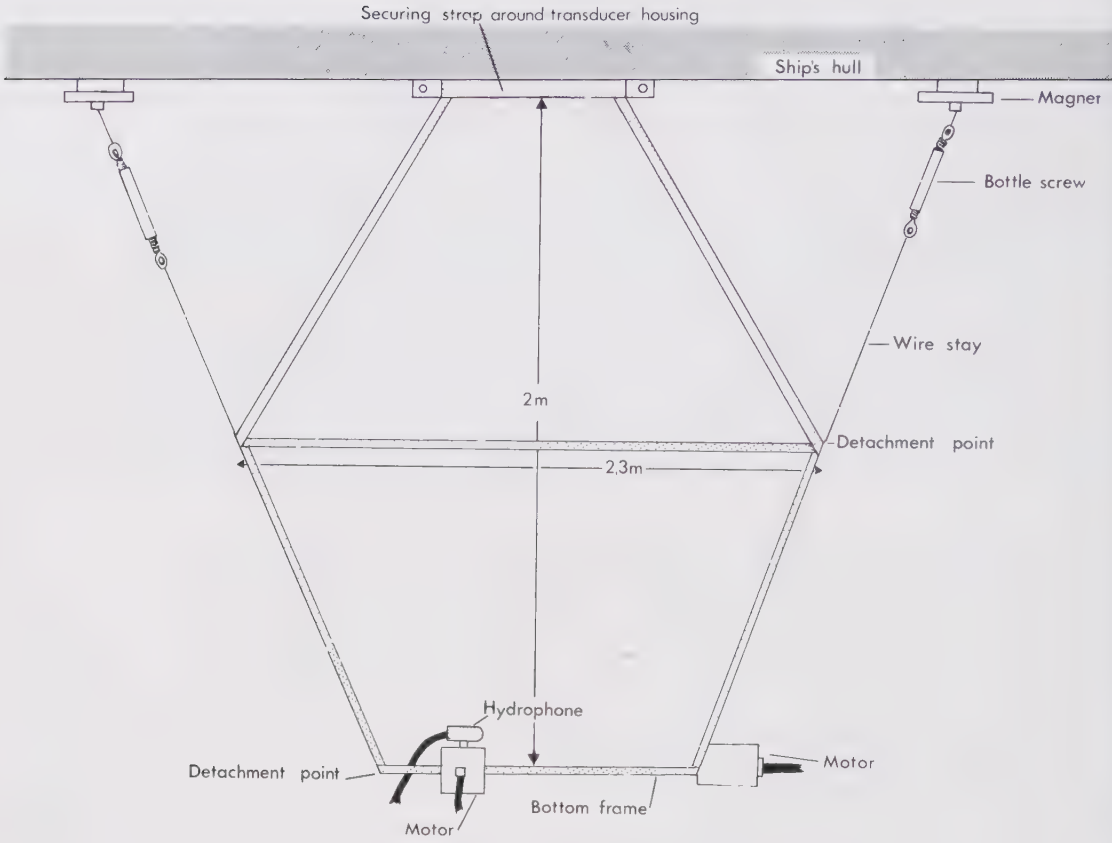

Fig. 2: Calibration rig attached to hull (not to scale)

sound intensity (or receiving sensitivity) at an angle θ off axis, $J_1(\phi)$ is the first-order Bessel function of argument ϕ, D is the diameter of the transducer and λ is the wavelength of the radiated sound wave.

From Figure 1 it can be seen that, in order to calibrate this particular transducer to within 10 per cent at a range of 2 m, the hydrophone must be positioned within 3,5 cm of the acoustic axis.

One of the positioning methods commonly employed is to suspend the hydrophone under the ship on a small frame which can be manipulated by ropes until the position giving the maximum received signal is found (Forbes and Nakken 1972). This method has the advantages of being simple and adaptable to any ship, but the manipulation is difficult and, particularly for narrow-beam transducers, the degree of positional control is not adequate for accurate calibration. Alternatively, the hydrophone can be mounted rigidly on the geometric axis of the transducer, but this has th disadvantage that the geometric and acoustic ax do not necessarily coincide. Although divers ca manually move the hydrophone to find the acoust axis more accurately, this task is particularly tediou because after each adjustment a time has to b allowed for the disturbance and aeration cause by the diver to die away before measurements ca be made. Finally, retractable hull-mounted calibr tion hydrophones incorporating remotely controlle positioning facilities have been used on some vessel These are manufactured commercially and provid the necessary positioning control, but they ar expensive and can only be used on the ship i which they are installed.

Apart from the various drawbacks mentioned none of the systems described is suitable for makin beam-pattern measurements because of the diff culty in all cases of moving the hydrophone in horizontal plane and measuring its displacemen

xis accurately.
cause of these problems with existing systems, w calibration system was designed and built. system is intended to allow precise remote rol of the hydrophone in the horizontal plane, relatively inexpensive and simple to install ny vessel, and to be adaptable to a wide range ips and transducers.

EQUIPMENT

eral

he rig (Fig. 2) basically consists of a rigid re frame carrying a hydrophone which can motely driven along two mutually perpendicu- xes in the horizontal plane. It is placed in tion by divers and attached to the hull by ns of a strap around the streamlined housing hich the transducer is mounted. (The high- uency transducers on the various vessels used he Sea Fisheries Institute are mounted in tical housings, so it is possible to use the rig ny of these vessels. For other installations, an ter frame would have to be used.) The rig is rigid by four adjustable wire stays fixed to ull by permanent magnets placed in position e divers. The magnets have a nominal vertical of 400 N each and are fitted with overlapping ing plates to allow them to be levered off y underwater. The rig can be buoyed and ed into position in a single piece, or if necessary be broken up into three separate sections and embled underwater.

hanical system

he bottom frame (Fig. 3) contains two orthogo- threaded brass rods, each of which is mounted stainless steel beam-track travellers (Fig. 4A). h rod is turned by a d.c. stepping motor fixed he frame. The rods are transversely coupled to h other through a threaded bush arrangement g. 4B), so that when the one rod turns, the er moves relative to it along its axis. This angement allows the hydrophone, which is fixed the upper rod, to be driven in either of the two ections (X and Y control). The motors can also driven simultaneously, allowing the hydrophone be moved continuously along the diagonal (XY ntrol).

The length of the thread on each rod is 1 080 mm and the pitch, 2,7 mm. This gives 400 turns on each rod. The motors are 12 V d.c. 20 W windscreen wiper motors which run at 40 r.p.m. If stepping continuously, the traversing speed is 1,8 mm • s^{-1} in the X and Y directions and 2,5 mm • s^{-1} along the diagonal.

The motors are sealed into water-tight compartments (Fig. 4A). Power and control signals are supplied to each motor individually through 3-core cables terminating in waterproof plugs which can be disconnected underwater. This facilitates manipulation of the rig underwater, enabling the cables to be left off the rig until it has been attached to the hull.

Electronic control unit

The electronic control system (Fig. 5), which is operated from the deck, consists of a 12 V d.c. power pack, forward and reverse controls (stepped or continuous modes) for each motor, two pulse counters which are incremented or decremented according to direction with each revolution, and a reset switch which allows the counters to be reset manually at any hydrophone position.

The direction of the motor is selected by choosing the appropriate polarity of the power supply through reversing switch S1. Switch S2 activates the relay which puts a start pulse onto the motor, causing it to turn and connect the power supply to the motor through the slip-ring arrangement (see Fig. 5). This arrangement keeps the motor turning for one revolution, after which it stops unless switch S2 is still on, in which case another start pulse is generated and the cycle is repeated. Each pulse is counted, and at the end of a complete traverse the counter generates a stop pulse which blocks any further action unless the direction is reversed.

Positioning accuracy

In assessing the performance of the system, the figure of merit is the accuracy attainable in finding the acoustic axis of the transducer and measuring the position of the hydrophone with respect to it.

The axis is found by moving the hydrophone in the X direction to give the maximum output, and then repeating this for the Y direction. The precision with which this can be done is determined essentially by the signal-to-noise ratio in the hydrophone output and the precision attainable in adjusting the hydrophone position. The latter is determined

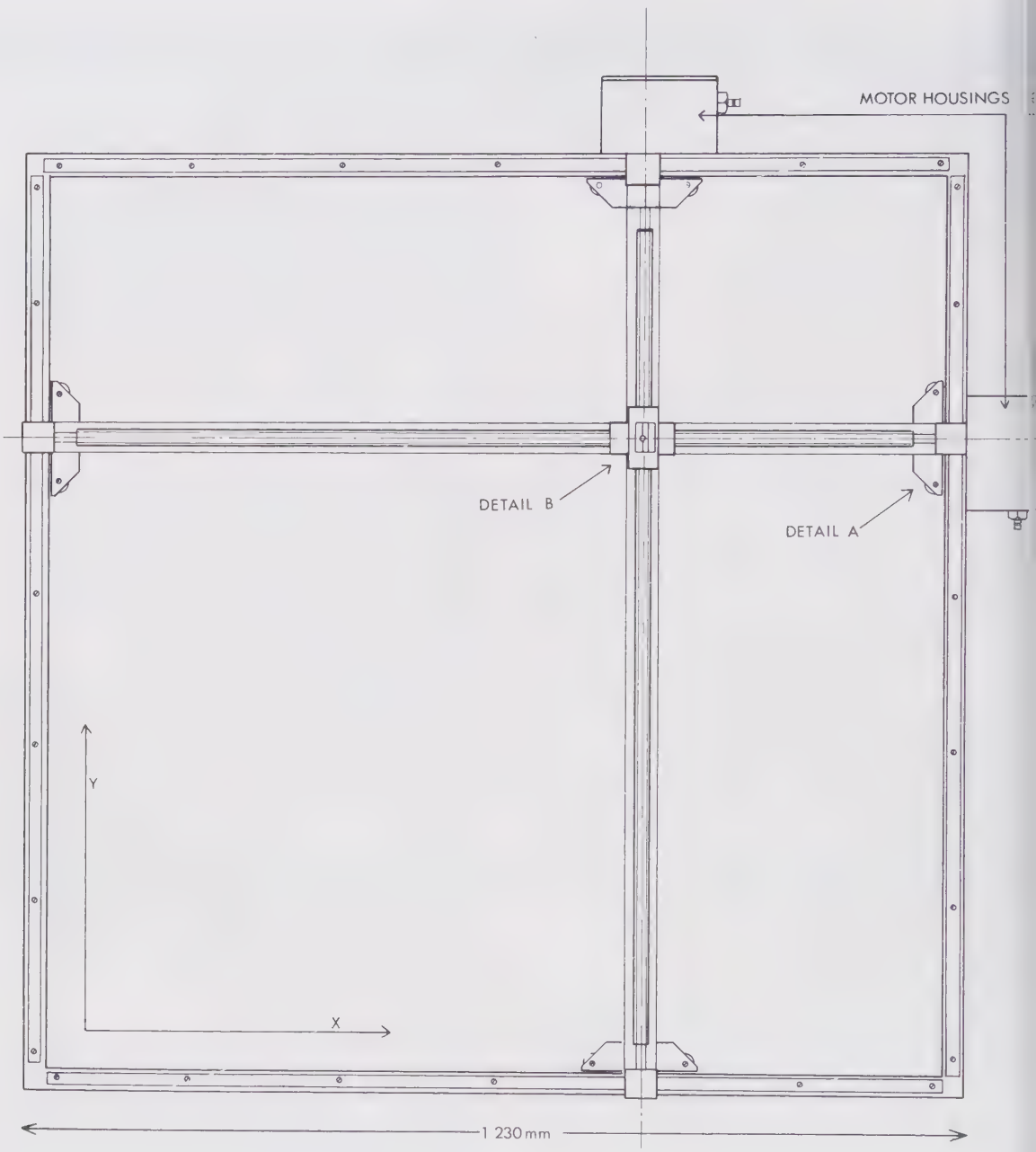

Fig. 3: Bottom frame of rig

by the minimum adjustment that can be made (in this case one turn, or a displacement of 2,7 mm in either direction), and the rigidity of the frame with respect to the transducer while the adjustments are being made.

Apart from the range, which is measur acoustically, the position of the hydrophone w respect to the transducer itself does not have

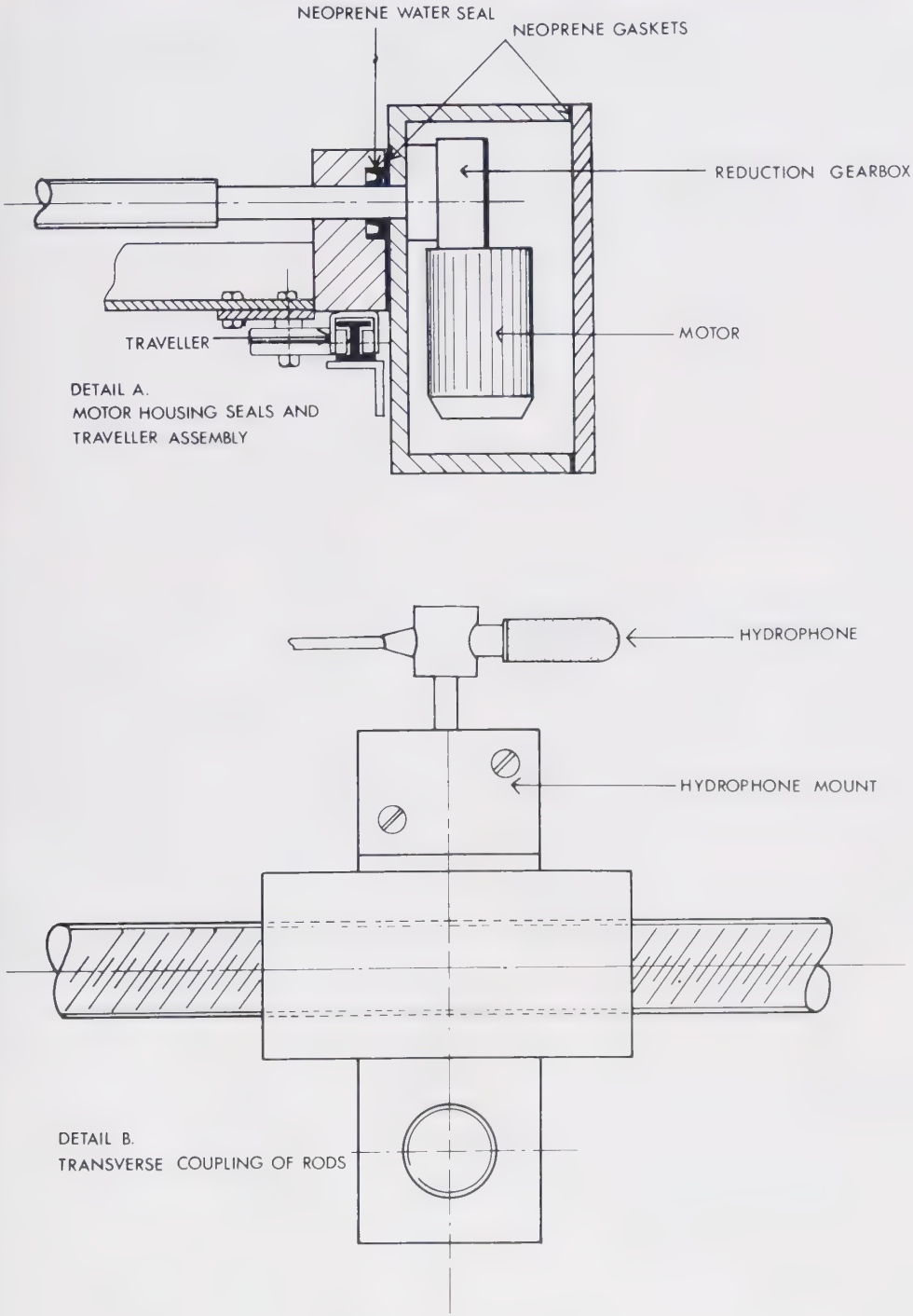

Fig. 4: Details A and B of Figure 3

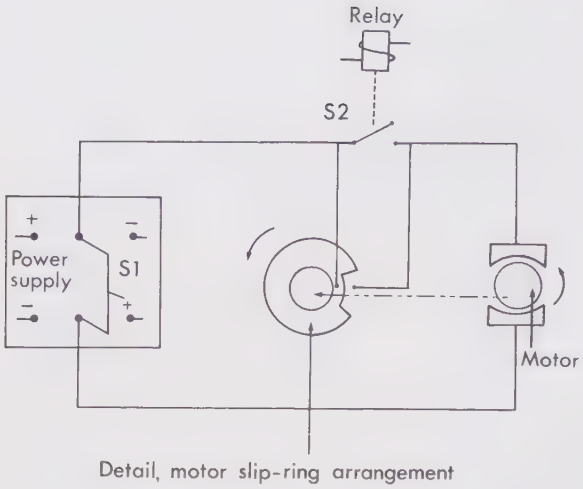

Fig. 5: Electronic control system

be known, thereby avoiding the need for precise positioning of the rig with respect to the transducer.

In order to determine beam patterns, the hydrophone is moved through the acoustic axis in the X, Y and XY (diagonal) directions in turn, and the output plotted as a function of displacement off axis. Assuming that the frame remains rigid during the course of the measurements, the positioning accuracy attainable here is determined by the accuracy with which the position of the hydrophone with respect to the frame can be read. In the absence of thread imperfections and backlash in the drive system (both of which are considered to be negligible), the position can be read off to within 2,7 mm, the pitch of the thread.

RESULTS

The system has been used to calibrate a 120-kHz 10 cm-diameter piston transducer on the South African Antarctic supply and research vessel, *S.A. Agulhas*. The theoretical beam width of this transducer, which has circular symmetry, is 7,2° (between 3 dB points). The theoretical near-field limit is 0,4 m (Kinsler and Frey 1962).

A team of three divers was used to attach the rig to the hull and to remove it after the measurements had been completed. The attaching was done in about two hours and the removal in about one hour. The rig remained in position for three days at a depth (bottom frame) of 9 m. During this

Table I: Readings of source level and receiving sensiti over a three-day period (full output power, 1,0 ms pulse length)

Date	Source level (dB ref. 1 Pa at 1m)	Voltage receivi response (dB ref. per Pa)
14/7/80	224,7	101,1
15/7/80	224,6	100,7
16/7/80	224,6	100,7

time, measurements were made on system sou level, receiving sensitivity, bandwidth and pu length. In addition, the transducer beam patte in the X, Y and XY directions were recorded.

The readings of source level and receivi sensitivity were consistent to within 0,5 dB o this period (Table I), which indicates the stabil of the rig. The ship lay in sheltered water alongsi the quay, and the weather was calm throughc the measurement period.

It was found that the precision in finding t axis was limited more by noise in the hydropho output than by any lack of control of the hyd phone position. At full transmitter power, t signal-to-noise ratio with the hydrophone near t axis was approximately 20 dB, which enabled t axis to be found consistently to within about turns (1,4 cm) in the X and Y directions. T system therefore enables the total calibration err from hydrophone misalignment to be kept belc 2,5 per cent (see Fig. 1), which is below the absolu calibration accuracy of the hydrophone.

The beam-pattern records, an example of whi is shown in Figure 6, were made by driving t hydrophone with a constant 120-kHz sinusoid signal, and by recording the output from the ech sounder receiver as the hydrophone was moved a constant rate in the appropriate direction. Betwe the −10 dB points a relatively clean trace w obtained (Fig. 6). Beyond this the sharp reductic in signal level, probably combined with increase reflections from the frame, caused the signal-t noise ratio to deteriorate markedly, making th trace from this region less useful. This problem i however, not of concern, because accurate knov ledge of the intensity of the beam on the outc edges of the main lobe is not necessary fc estimating abundance, because targets in this regic make a relatively low contribution to the receive echo intensity. Bodholt (1977) has shown that, fc this particular transducer, targets lying outsic the −9 dB point will, on average, contribute onl 1 per cent of the total energy received.

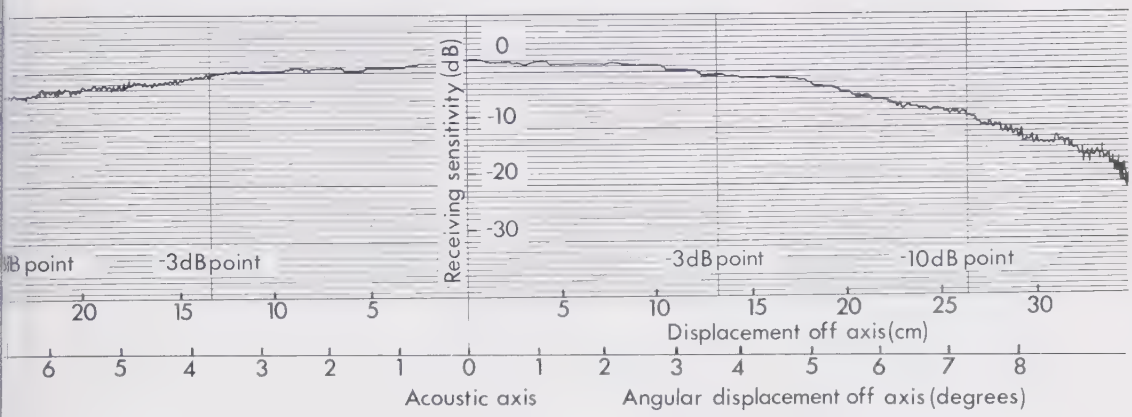

Fig. 6: Beam pattern in X direction

CONCLUSIONS

he calibration rig has been found to be relatively le to install and remove, and to provide uate positioning control both for finding the of a narrow-beam transducer mounted on the and for mapping its beam pattern in the al portion of the main lobe. The rig can be ted to any ship with a suitable locating and ing arrangement in the vicinity of the transdu- If the rig is to be used for a transducer whose ield zone extends beyond 2 m (e.g. narrow- , low-frequency transducers), the frame would to be adapted to increase the distance between ansducer and the hydrophone.

ith the advantage of ease of handling, high e of positional control in the horizontal plane, adaptability to a wide range of ships and sducers, the rig is considered to be a useful for quantitative acoustic studies in fisheries arch.

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GEOGRAPHICAL VARIATION IN THE VITAMIN A CONTENT OF LIVERS OF ADULT MALE CAPE FUR SEALS *ARCTOCEPHALUS PUSILLUS*, 1941–1949

P. D. SHAUGHNESSY

Vitamin A was produced commercially from the livers of Cape fur seals *Arctocephalus pusillus* harvested mainly for skins and blubber oil in southern Africa between 1941 and 1949. A previous laboratory study showed that livers of adult males (bulls) had a higher concentration of vitamin A than those of juveniles, and that livers of bulls on the South Coast had a higher concentration than those on the West Coast. Vitamin A was processed from an annual average of 23,2 metric tons of liver (range 3,8 — 48,8 tons). Data from commercial production of vitamin A support an earlier study on regional differences in vitamin A concentration of bull livers. Furthermore, data from the collections in 1947 and 1948 and the published laboratory determinations have been analysed statistically. They indicate that vitamin A concentration of bull livers decreases with distance along the coast from the easternmost colony at Black Rocks in Algoa Bay to the northernmost one at Cape Cross and that the relationship between the two parameters is linear. This variation parallels that of vitamin A levels in Cape hakes, prey species of Cape fur seals. These observations suggest that Cape fur seal bulls feed in the vicinity of their breeding colonies in the period immediately preceding the breeding season.

Vitamine A uit die lewers van Kaapse pelsrobbe is tussen 1941 en 1949 in Suider-Afrika op kommersiële grondslag geproduseer. Hierdie robbe, *Arctocephalus pusillus*, word eintlik veral met die oog op hul velle en spekolie gejag. Uit 'n vorige laboratoriumstudie het geblyk dat die lewers van volwasse bulle 'n hoër konsentrasie van vitamine A bevat as dié van jongrobbe, en dat die lewers van bulle aan die Suidkus 'n hoër konsentrasie bevat as dié aan die Weskus. Vitamine A is gehaal uit 'n jaarlikse gemiddelde van 23,2 metrieke ton lewer (bestek 3,8 — 48,8 ton). Gegewens uit die kommersiële produksie van vitamine A stem ooreen met 'n vroeër studie oor gebiedsverskille in die vitamine-A-konsentrasie van bul-lewers. Daarbenewens is 'n statistiese ontleding gedoen van die versamelings in 1947 en 1948 en die gepubliseerde laboratoriumbepalings. Dit dui daarop dat die vitamine-A-konsentrasie van bul-lewers algaande afneem, van Swartrots in Algoabaai, die kolonie wat die verste oos lê, tot by die noordelikste by die Kruiskaap, en dat die verhouding tussen die twee parameters lineêr is. Hierdie tendens is soortgelyk aan dié van vitamine-A-vlakke by stokvissoorte, spesies waarop die Kaapse pelsrob jag maak. Hierdie waarnemings dui daarop dat Kaapse pelsrobbulle in die tydperk net voor die paartyd in die omgewing van hul teelkolonies hul prooi jag.

ape fur seals *Arctocephalus pusillus pusillus* outhern Africa have been harvested commer- y for skins and blubber oil since the seventeenth ury (Rand 1972). Their livers were used as a mercial source of vitamin A from 1941 until 9. Studies aimed at promoting the utilization aw materials from annual harvests and based n examination of livers collected from 1941 to 4 showed that livers of adult males (bulls or s) from colonies off the South Coast contained ater concentrations of vitamin A than those m colonies off South West Africa (Black *et al.* 45). Furthermore, they showed that the concen- tion of vitamin A was higher in livers of bulls n in those of juveniles. The two age classes re studied as they formed the basis of annual rvests. A similar age-variation in vitamin A ncentration of livers has been described for rthern fur seals *Callorhinus ursinus* (Sanford *et* 1949) and for Australian fur seals *Arctocephalus sillus doriferus* (Southcott *et al.* 1974).

Because differences in the vitamin A content of the livers of Cape fur seal bulls from different colonies might provide a useful means of distinguishing between discrete populations, further data from the industry have been assembled from the files of the Division of Government Guano Islands (G.G.I.) and are presented here. Some additional information is included on this short episode of the sealing industry in southern Africa.

METHODS

Seals were harvested at the colonies (Fig. 1) and their livers collected, sliced and packed into drums with borax (a preservative) by the G.G.I. who sold them to private industry for processing. Information on the production of vitamin A from seal livers has been obtained from correspondence between the G.G.I. and producers of vitamin A from G.G.I. files numbered 17/7 and entitled "Sealing, Seal Livers" in two volumes dated from 30 June 1941 to

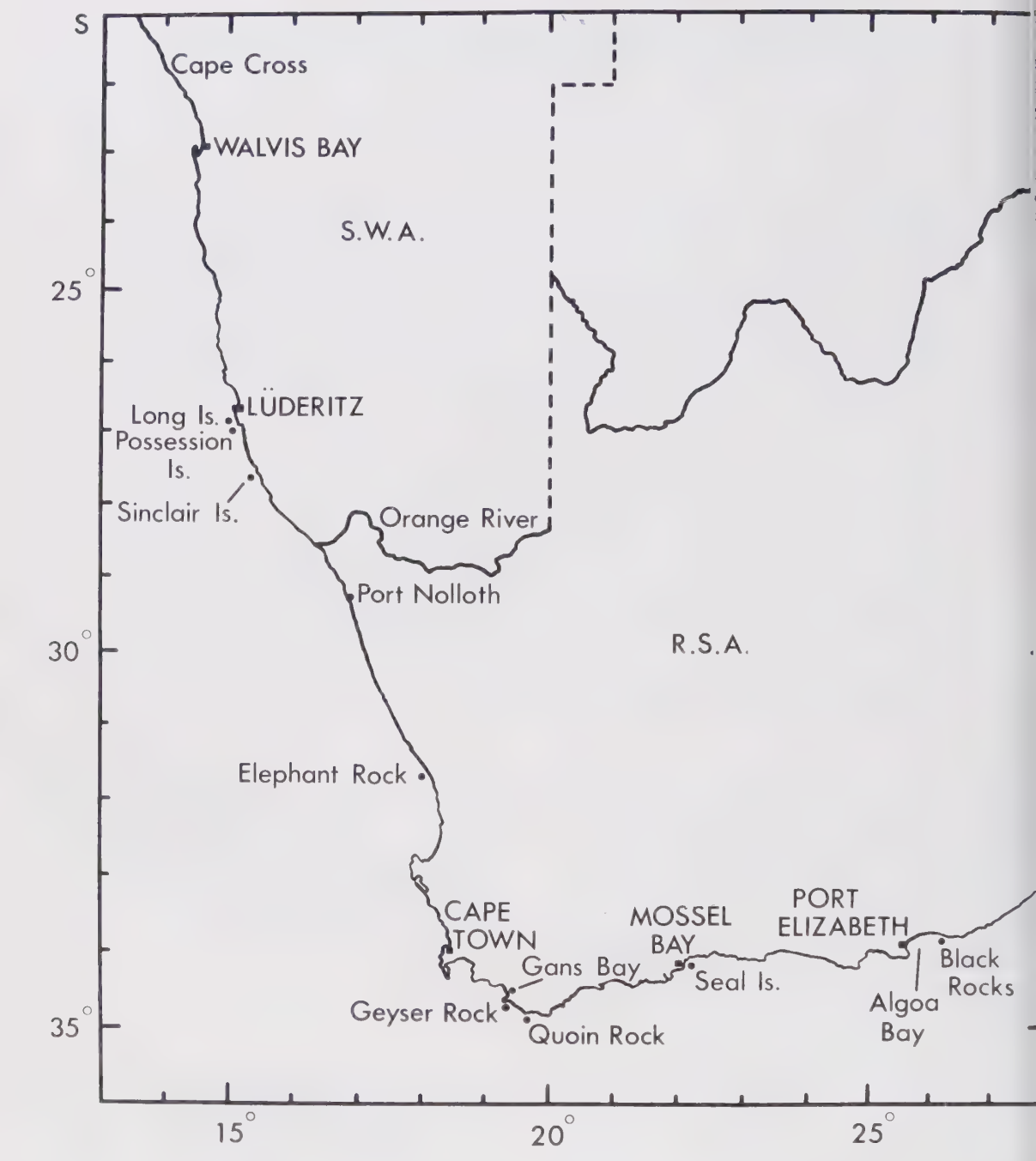

Fig. 1· Sources of Cape fur seal livers used for determining vitamin A production and other localities mentioned in the text

December 1946 and from 1 January 1947 to 30 ember 1953.

lmost all of the livers processed were collected n bulls which were harvested during their eding season from late October to December. ose from juveniles (mostly in their first year) e collected during the winter harvest between e and September (Rand 1972). Although most rs were not processed until the year following ection, production figures provided here refer he year in which the seals were harvested.

n some places in the G.G.I. files, data for clair and the Long Islands are attributed to ssession Island". The latter has no seal colony, was used as a base for bull-sealing operations Sinclair and Long Islands. No bulls were taken m a third island in that area (Albatross Rock) ing this period (Rand 1972). Similarly, data for seal colonies on Black Rocks in Algoa Bay l Geyser Rock are attributed in the files to Bird nd and Dyer Island respectively. The latter nds do not support seal colonies, but were d as bases for sealing operations on nearby ck Rocks and Geyser Rock (Rand *op.cit.*).

THE INDUSTRY

t least four companies were involved in the duction of vitamin A from seal livers: Marine ducts (Pty) Ltd of Salt River, Cape Town, h later became Marine Products Corporation; an Products (Pty) Ltd of Gans Bay; South ican Sea Products (Pty) Ltd of Cape Town (for 945 harvest only); Vitamin Oils Ltd of Cape wn. Marine Products was one of the original panies involved and the only processor for ast three seasons. Several companies processed rs each year from 1942 to 1945.

n 1941, livers were collected from juveniles y; in 1942 and in 1944 they were collected from th juveniles and bulls. In other years, livers of lls only were processed because they had a her vitamin A content.

Initially the price paid to the G.G.I. for livers s entirely dependent on their mass. Because of wide variation in vitamin A content, the rchase price was later based on the results of amin A analyses. The price, in pence per pound liver, was calculated from the formula

$$E \times \text{percentage of oil from liver} \times \frac{n}{1\,000}$$

where E was the absorbance of vitamin A in a sample of the liver oil measured spectrophotometrically as $E^{1\%}_{1cm}$328 mμ. The value of n was decided upon by the buyer and seller. It increased from 13,5 in 1943 and 1944 to 20 in 1945 and 33 in 1946. This formula was first suggested by Marine Products (Pty) Ltd in a successful tender dated 6 December 1943 for a consignment of livers from bulls harvested at Geyser Rock and Seal Island, Mossel Bay.

This arrangement was satisfactory, provided drums containing livers from different colonies were kept separate. All material from the 1946 harvest was processed by one company, which did not pay sufficient attention to its source. Payment to the G.G.I. was finally made that year on the basis of the vitamin A level in liver oil of seals from the "west coast" and "east coast" (Table I). As the G.G.I. was dissatisfied with the 1946 production figures, it contracted in the following year with another processor. It was to be reimbursed in that and subsequent years according to the rate paid by the British Ministry of Food for oils containing vitamin A.

In some years several shipments of bull livers were sent to the processor from a particular area or colony. Because information concerning the vitamin A content of the livers was provided for each shipment, the vitamin A level for each one is presented in Table I. These values are displayed graphically in Figure 2 for most of the years in which livers were collected.

The amount of liver collected by the G.G.I. and their income from sales of liver for vitamin A extraction (Table II) show that the former ranged from 3,8 to 48,8 metric tons annually, with an average of 23,2 tons. The amount collected gradually increased up to 1947. Reasons for the subsequent decline and for the cessation of the industry after the 1949 harvest are not apparent from correspondence on the files, but may have resulted from the synthesis of vitamin A on a commercial scale which commenced in the late 1940's (Sebrell and Harris 1954).

VITAMIN A CONTENT OF BULL LIVERS

In order to compare the vitamin A content of livers of bulls from different colonies, a convenient measure is the number of international units of vitamin A (IUA) in the liver oil per unit mass of liver. Transactions on the G.G.I. files for the

Table I: Vitamin A content of livers of Cape fur seal bulls from commercial production

Seal colony	Distance from Black Rocks (km)	Vitamin A concentration*						Value of liver† 1948
		1943	1944	1945	1946	1947	1949	
Black Rocks, Algoa Bay	0	—	—	—		8 222	—	74,94
Seal Island, Mossel Bay	390	19 924	15 287	—		7 699	6 484	72,10
Quoin Rock	650	—	—	10 857 8 298	East coast‡ 9 800	5 359 6 479 6 188	4 500	50,57 56,46
Geyser Rock	675	12 536	13 129			4 034	—	41,40
Elephant Rock	1 100	—	—	—		—	—	—
Sinclair Island	1 595	—	3 269 4 392	3 214	West coast 2 131	2 607	—	—
Long Islands	1 700	—	4 158 1 696 785	3 044		1 370	—	9,02

* In international units of vitamin A per gramme of liver
† In pence per pound of liver, based on vitamin A content
‡ Includes Black Rocks, Seal Island and Geyser Rock

processing of bull livers present these data for the 1947 and 1949 harvests only (Table I). For the harvests from 1943 to 1946, the mass of liver processed, percentage of oil in the livers and the absorbance value ($E^{1\%}_{1cm}$328mμ) were provided by the processor. From these data the concentration of vitamin A in IUA per gramme of liver processed can be calculated as

$$E \times \frac{\text{percentage of oil from liver}}{100} \times \text{conversion factor.}$$

A factor of 1 600 was used to convert absorbance to vitamin A content by Black *et al.* (1945). Later, one of these authors advised the Superintendent of the G.G.I. that this should be replaced by 1 740. However, subsequent correspondence on the files indicated that a value of 1 600 was used until 1948, when the value 1 200 was introduced for livers collected in the 1947 harvest, following the practice of the British Ministry of Food for whale oil. Where vitamin A concentrations have been calculated now and inserted in Table I, a conversion factor of 1 600 has been used.

For the 1948 harvest, the mass of liver processed and its value (in pence per pound) were provided by the processor for each colony. Although the price paid for livers was dependent upon their yield of vitamin A, it is not clear how much was paid per million IUA. Consequently these data have not been converted into vitamin A concentrations.

For the 1947 and 1948 harvests, sufficient dat are available to allow the calculation of linea regression equations of the vitamin A level of bu livers on distance from the easternmost colon (Black Rocks in Algoa Bay). For the 1947 data th equation is

$$Y_1 = 8\,344 - 3{,}93\,d,$$

where Y_1 is the vitamin A concentration in IU

Table II: Quantity and value of unprocessed livers fro Cape fur seal bulls sold by the Division of Governmer Guano Islands to vitamin A processors

Year	Quantity of liver (kg)	Value
1942	11 360	£313··1s··0d
1943	3 779	£422··0s··6d
1944	22 463*	£1 350··5s··0d*
1945	28 707	£2 122··17s··9d
1946	35 767	£2 256··16s··5d
1947	48 767	£8 642··9s··5d
1948	29 707	£5 952··19s··9d
1949	6 532	£361··4s··6d†

* Includes at least 1 110 kg of livers from juveniles of whic 677 kg was valued at £11··10s··10d
† Includes payment for 22 kg of shark liver

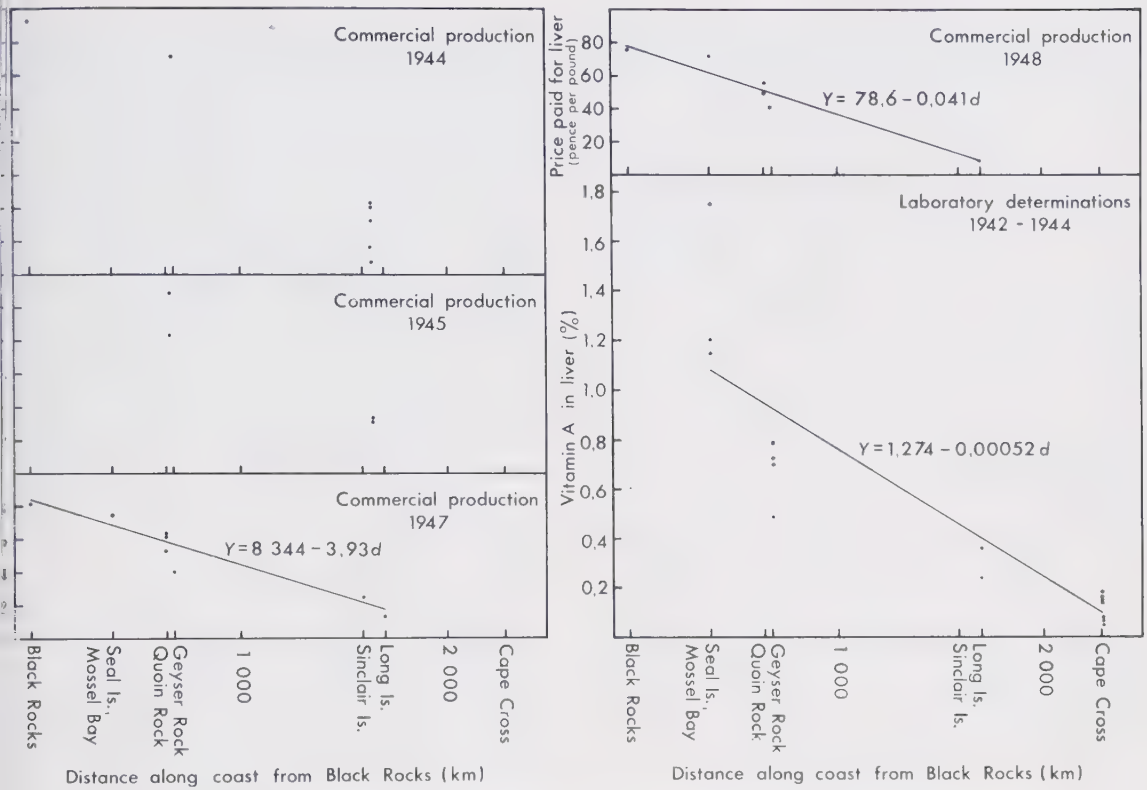

Fig. 2: Vitamin A content of livers of Cape fur seal bulls from various colonies (in the regression equations *d* is the distance from Black Rocks in kilometres)

gramme of liver and *d* is the distance (km) m the easternmost colony. The correlation fficient *r* is 0,940 and the regression is significant e 0,1-per-cent level ($t = 6,75$, with six degrees eedom).

or the 1948 data, the regression equation is

$$Y_2 = 78,6 - 0,041\ d,$$

ere Y_2 is the price paid for livers in pence per und, and *d* is again distance (km) from the sternmost colony. The correlation coefficient *r*),962 and the regression is significant at the 1- r-cent level ($t = 7,04$, with four degrees of edom).

In addition to information from the commercial oduction of vitamin A, laboratory determinations the Department of Chemistry at the University Cape Town (Black *et al.* 1945) of the levels in ers of samples of 5 to 50 bulls taken in four colonies between 1942 and 1944 are available (Table III). From these data another regression equation of vitamin A level of bull livers on distance from the easternmost colony can be calculated, namely

$$Y_3 = 1,274 - 0,00052\ d,$$

where Y_3 is the percentage of vitamin A in livers, and *d* is again distance (km) from the easternmost colony. The correlation coefficient *r* is 0,883 and the regression is significant at the 0,1-per-cent level ($t = 7,04$, with 14 degrees of freedom).

The same laboratory also made vitamin A determinations of bull livers from the 1945 harvest and advised the Superintendent of the G.G.I. that those from the "east coast" contained $24,9 \times 10^3$ IUA per gramme of liver (11,3 million IUA per pound) and those from the "west coast" contained $4,2 \times 10^3$ IUA per gramme of liver (1,9 million IUA per pound).

Table III: Vitamin A concentration of livers of Cape fur seal bulls (as percentage vitamin A in liver) from laboratory determinations (condensed from Table IV of Black *et al.* [1945])

Seal colony	1942		1943		1944	
	Vitamin A concentration	*n*	Vitamin A concentration	*n**	Vitamin A concentration	*n*
Seal Island, Mossel Bay			1,15 1,20 1,75	12 — —		
Geyser Rock	0,784	—	0,727 0,703 0,490	5—6 50 —		
Long Islands	0,358	—	0,252	—		
Cape Cross			0,053 0,080 0,151	— 15 27	0,155 0,165 0,189 0,067	— — — —

* Sample sizes obtained from correspondence on G.G.I. files with Miss M. M. Black of the Department of Chemistry at University of Cape Town
— Sample size not known

DISCUSSION

Data presented here from commercial processing of livers of Cape fur seal bulls support the statement of Black *et al.* (1945) that the concentration of vitamin A in livers is greater for colonies on the South Coast than for colonies on the West Coast. Linear regression analyses based on the commercial production data and on the published laboratory determinations indicate that vitamin A levels of bulls decrease with distance along the coast from the easternmost colony at Black Rocks in Algoa Bay to the northernmost colony at Cape Cross.

The data presented in Tables I and III may not be reliable indicators of the actual level of vitamin A in livers of Cape fur seal bulls for two reasons. Firstly, it was not always clear which factor was used to convert spectrophotometric absorbance values to vitamin A content. Secondly, some degradation of vitamin A in the livers may have already occurred when the determinations were made. Provided batches of livers from the various seal colonies were treated similarly, the data should be suitable for comparative purposes. That the same geographical trend was apparent in each of several years indicates that this proviso was satisfied reasonably well.

Black *et al.* (1945) suggested that the geographic variation they observed in vitamin A level of bu livers might be related to variation in the vitam A content of the seals' food. This suggestion w followed up by Roux and Molteno (1946) for th Cape hakes (*Merluccius* spp.), prey species of th Cape fur seal (Rand 1959). Roux and Molter *(op.cit.)* showed that the vitamin A level of live of hake trawled near Port Elizabeth was high than in those trawled near Cape Town, which i turn was higher than in those from Port Nollot Archer (1948 a) found similar results for this specie Therefore the trend in vitamin A levels in th livers of seal bulls parallels that of one of its pre species. Archer (1948 b) found similar geographic variation in vitamin A levels of livers of the soupfi shark *Galeorhinus zyopterus* (subsequently know as *G.galeus*), which suggests that such variatio may be common among marine organisms off th coast of southern Africa.

On the other hand, variation in vitamin A leve of the liver of the Cape spiny dogfish *Squalu acutipinnis* (subsequently referred to as *S. fernand nus*) was independent of catch locality (Arche 1948 a).

Geographical variation in vitamin A level c livers of the fish species reported to be the mos important prey of Cape fur seals by Rand (1959 i.e. horse mackerel *Trachurus trachurus* an pilchard *Sardinops ocellata,* has not been examined although vitamin A levels of the oil of these specie have been reported (Black and Schwartz 1950).

A marked difference in the vitamin A level o livers of juvenile and bull Cape fur seals wa noted by Black *et al.* (1945), with the higher level recorded in bulls. The difference could have bee influenced by the sampling methods used, becaus most of the juveniles sampled came from winte harvests between July and September, and bull from harvests in November or December. If th seals' food had a lower vitamin A content in lat winter than in early summer, this might have bee reflected in the livers of seals killed during thes periods. Such seasonal differences occur in th vitamin A content of another prey species of th Cape fur seal, the snoek *Thyrsites atun.* Rapson *e al.* (1944) showed that the vitamin A content o snoek livers decreased in winter, and they relate it to an increase in gonad size. However, data presented by Black *et al. (op. cit.)* for vitamin A content of livers of seals of three age classes (pups juveniles and bulls) sampled at Cape Cross i November 1944 suggested that the most importan factor influencing the vitamin A level of the liver of Cape fur seals at the colony was their age.

ne vitamin A level of livers of laboratory rats
i increases after the ingestion of large amounts
itamin A and remains high for several weeks
nonths (Davies and Moore 1948, Moore 1970).
vitamin A level of other mammals (including
e fur seal bulls) is likely to be similarly
endent upon their feeding regime. Therefore,
observations presented here, considered with
geographical variation in the vitamin A level
Cape hake livers, suggest that Cape fur seal
s feed in the vicinity of their breeding colony
ne period immediately preceding the breeding
son. This conclusion agrees with the statement
Rand (1959) that the seals of each colony form
y discrete units. A more reliable means of
nonstrating fidelity of seals to their natal colony
ld be provided by an electrophoretic study of
chemical markers or the recovery of tagged
eding seals where they were marked as pups.

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DETERMINATION OF METAL CONCENTRATIONS IN MARINE FISH TISSUES BY ATOMIC ABSORPTION SPECTROSCOPY: A COMPARISON OF RESULTS AFTER WET DIGESTION OF FREEZE-DRIED AND NON-DRIED SAMPLES

P. CHAPMAN and A. J. WYLIE

A comparison of the metal concentrations obtained from the analysis of 11 species of fish following wet digestion of freeze-dried and non-dried samples has shown that the results depend to a large extent on sample size. A cumulative probability plot has shown that the results obtained from non-dried samples are less prone to error from contamination.

'n Vergelyking van die metaalkonsentrasies verkry uit die ontleding van 11 visspesies na nat-vertering van vries-gedroogde en ongedroogde monsters het aangetoon dat die resultate grotendeels afhang van die monstergrootte. 'n Kumulatiewe waarskynlikheidsuitstipping het getoon dat die resultate van ongedroogde monsters verkry, minder onderhewig is aan foute as gevolg van kontaminasie.

Before biological samples can be analysed for tal content by atomic-absorption spectroscopy y must be dissolved. Generally, strong acids or d mixtures such as nitric/perchloric are used this digestion step, and many studies have n published on such wet-ashing methods. Before sample is treated with acid, homogenization oven-drying (Watling 1978), freeze-drying urie and Peisach 1977) or irradiation by ultra-let (Lobel 1978), microwave (Barrett *et al.* 1978) gamma radiation (Batley and Farrar 1978) are loyed.

eavy metals under investigation in marine ution studies occur generally at trace levels, therefore any equipment and chemicals used ng analysis need to be as free as possible from se elements. Accordingly, the fewer handling ps there are in a given analysis, the less will be chance for such contamination to occur.

osses of analyte elements have been reported Fourie and Peisach (1977) during freeze-drying, by Watling (1978) during oven-drying above °C. The present study was undertaken to test feasibility of omitting the freeze-drying step rrently in use at the Sea Fisheries Institute, and compare the results obtained after wet digestion freeze-dried and non-dried samples. There are ree major advantages of omitting this step.

i) Sample handling would be speeded up. At present this is limited by the rate at which samples can be freeze-dried.

ii) The potential metal loss owing to the evaporation of volatile metallo-organic compounds, as discussed by Fourie and Peisach (1977) and Watling (1978), would be eliminated.

iii) Two potential sources of contamination, the freeze-drying flask with its associated handling operations, and the grinding step during which the freeze-dried sample is ground in a pestle and mortar, would also be eliminated.

METHODS

Present laboratory freeze-drying method

The preparative method used at the Sea Fisheries Institute since 1974 is that of Fourie (1976). It is described here to show how eliminating the freeze-drying step could possibly result in a decrease of contamination by or loss of analyte metals. All glassware and plasticware used in the analysis was washed in a solution of Merck Extran, kept filled with 6 M hydrochloric acid for 24 h before rinsing with glass-distilled water, and then inverted on clean paper towel to allow to drain.

In the method of freeze-drying used at present, a sample of fish (see Table I) is weighed into a tared freeze-drying flask and deep-frozen for 24 h. The mouth of the flask is covered during this period. The flask and contents are then connected to the freeze-drier and freeze-dried at $-60°C$ under a vacuum of at least 13,3 Pa for 48 h. The flask and contents are reweighed, and the sample ground to a powder inside the freeze-drying flask with a teflon pestle. A known mass (approximately 2 g) of powdered sample is placed in a tall-form 150-mℓ glass beaker prior to acidification.

Sample size

For comparison of the two methods, samples of 80 fish were taken and their metal content was

Table I: Species of fish sampled and the masses taken for analysis

Species	Flesh samples		Liver samples	
	Number	Mass range (g)	Number	Mass range (g)
Kingklip *(Genypterus capensis)*	9	19,6-41,4	—	—
Monkfish *(Lophius piscatorius)*	10	2,5-42,5	—	—
Gurnard *(Trigla capensis)*	9	5,3-19,1	—	—
Rattail *(Coelorhynchus fasciatus)*	14	5,9-39,2	7	0,27-3,45
John Dory *(Zeus faber)*	20	4,8-29,1	9	0,8-10,2
Hake *(Merluccius* sp.)	2	9,8-12,0	1	5,6
Skate (*Raja* sp.)	8	3,7-12,9	4	1,9-7,4
Sawfish (*Pristis* sp.)	2	7,6-43,1	1	1,0
Shark (*Rhinobatus* sp.)	4	5,2-8,9	2	1,5-1,8
Dogfish (*Mustelus* sp.)	2	5,0-6,9	1	1,3

analysed by both. It is known that heavy metals accumulate in the liver of many fish species (Bryan 1976), and therefore both white flesh and liver tissue were used. The size ranges of the different samples are shown in Table I. A large size range was chosen in an attempt to establish the optimum sample mass for such experiments. Liver samples were smaller than muscle samples because of their expected higher metal content and because they contain a large percentage of oily material which is often very difficult to oxidize.

Acid digestion

Concentrated nitric acid (Hopkins and Williams AA grade, 40 mℓ) was added to both the freeze-dried and non-dried samples, and both were allowed to stand overnight in a fume cupboard protected from direct atmospheric deposition. The initial digestion process then took place slowly at room temperature without the danger of frothing which can occur when samples are placed directly onto a hotplate. The samples were subsequently heated on a hotplate, calibrated to keep the temperature of the solution below 95°C, until less than 1 mℓ of acid remained. Where digestion was not completed, additional nitric acid was added and the heating step repeated. When large samples were digested, it was sometimes necessary to add over 120 mℓ of nitric acid, particularly for liver samples, but less than 80 mℓ normally sufficed. Concentrated perchloric acid (Hopkins and Williams AA grade, 5mℓ) was then added to the sample, and digestion allowed to proceed until less than 0,5 mℓ liquid remained. The beakers were removed from th hotplate and allowed to cool. Concentrated hydr chloric acid (Merck Suprapur, 12 drops) was adde the solution was warmed, diluted with a litt distilled water and made up to volume in a 25-m flask. Any insoluble residue was filtered off wit Whatman 541 filter paper and the filtrates we stored in screw-top plastic containers.

Blanks were obtained by taking concentrate nitric acid (40 mℓ) through the same proces Concentrations of iron, copper and zinc in th acid were calculated in $\mu g \cdot m\ell^{-1}$ and, dependin on the volume of acid used for the fish sample subtracted from the initial results. Typical blan values for these elements were: iron 0,2 $\mu g \cdot m$ zinc 0,1 $\mu g \cdot m\ell^{-1}$ and copper 0,01 $\mu g \cdot m\ell^{-1}$.

Atomic-absorption analysis

The samples were analysed for zinc, coppe and iron using a Varian Techtron AA6 atomic absorption spectrophotometer with an air-acetylen flame and hollow-cathode lamps adjusted to giv maximum absorption for each element. Backgroun correction was used but standards were not matrix matched because matrix effects were considered to be insignificant (R.J. Watling, University o Port Elizabeth, personal communication).

Zinc, copper and iron were chosen because n evidence of volatilization of any metallo-organic of these elements during freeze-drying has bee reported.

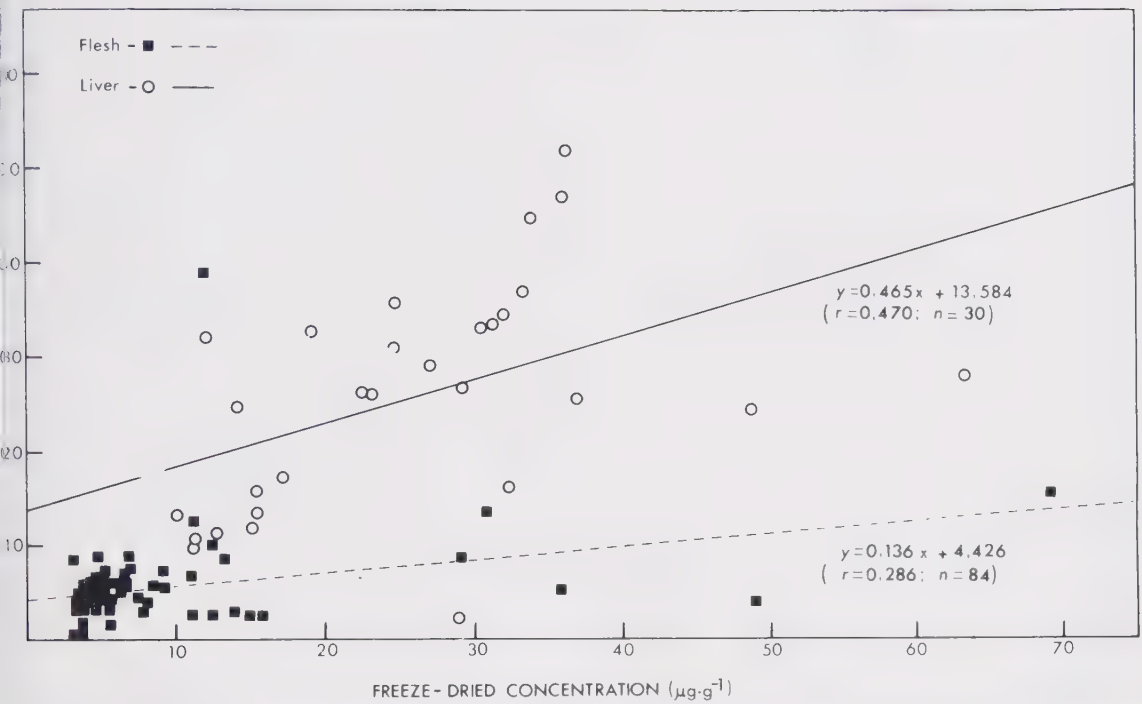
RESULTS

Results of analyses are given in microgramme per gramme of the original undried fish. Thi would normally be considered as being on a "we weight" basis. In this and succeeding section reference to "dried" and "non-dried" refers t samples analysed with and without an intermediat freeze-drying step.

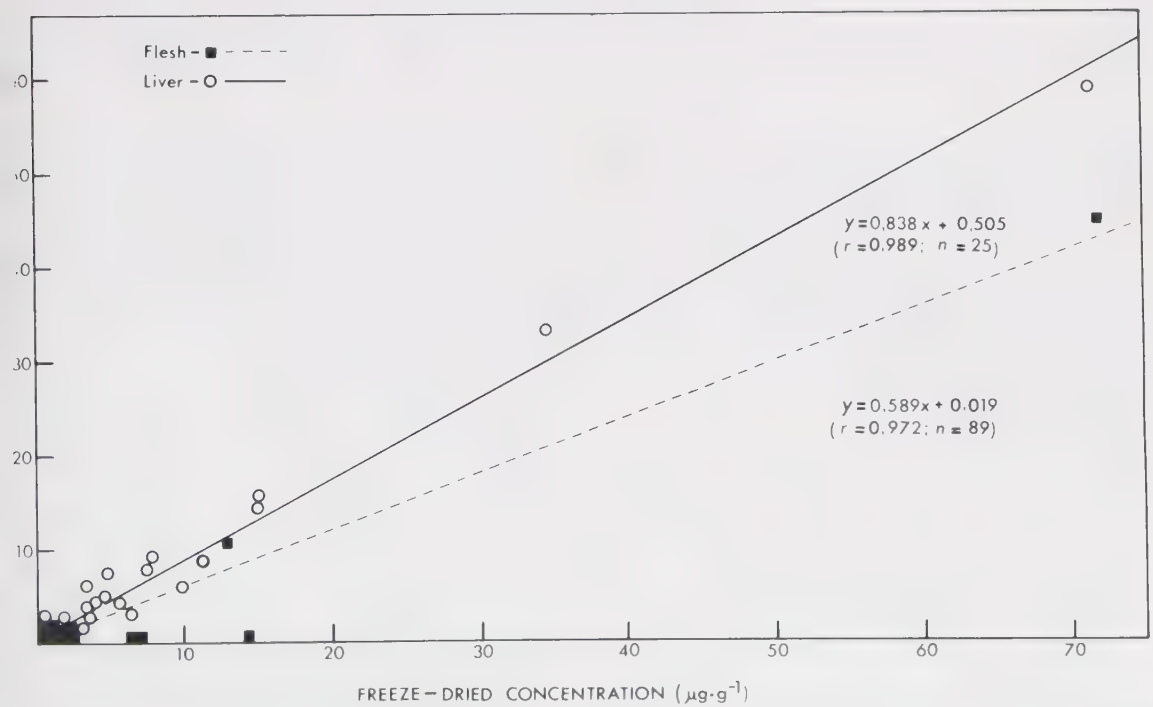
Wet-ashing of dried and non-dried samples

The results from dried and non-dried sample were compared directly for each element an regression equations calculated by least-square analysis (Figs. 1-3). Correlation coefficients *(r)* and number of samples *(n)* are also shown on th Figures.

Apart from the iron-in-flesh results, which ar significant at the 2-per-cent level, these correlation



1. Concentration of zinc in fish measured after wet digestion of samples of freeze-dried and non-dried material



2. Concentration of copper in fish measured after wet digestion of samples of freeze-dried and non-dried material

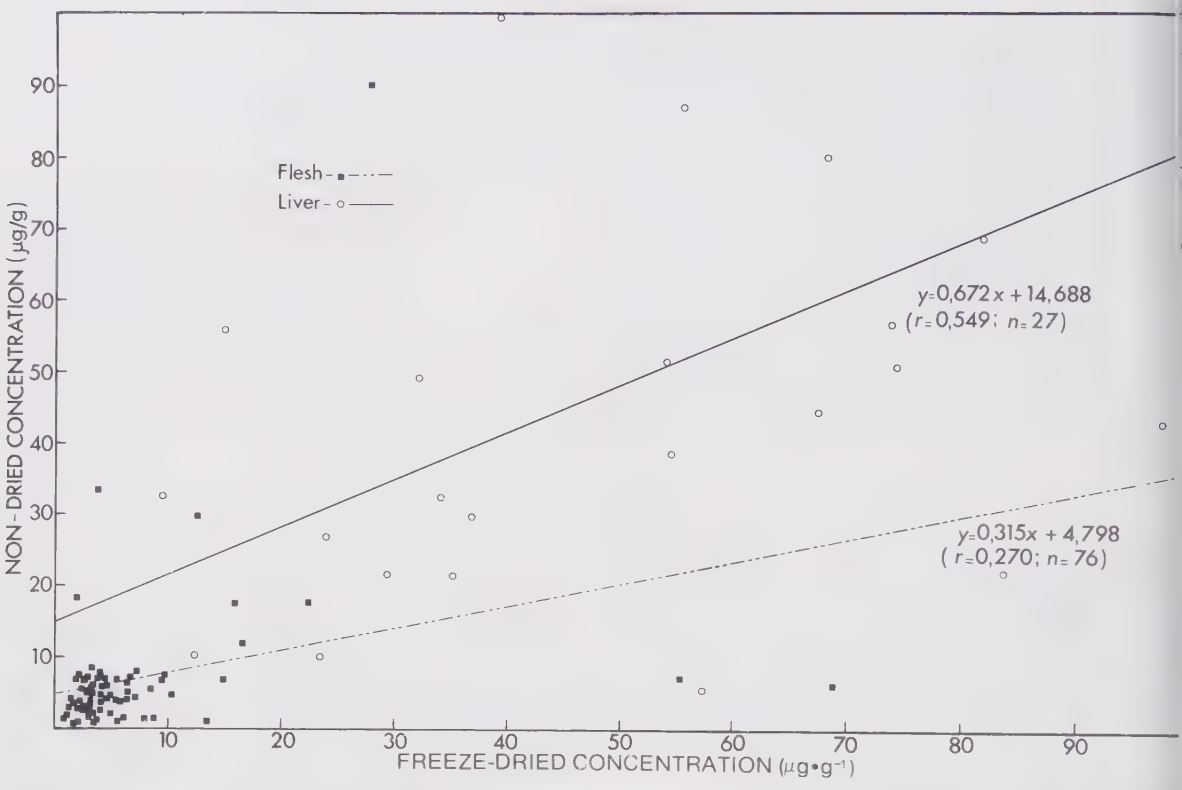


Fig. 3: Concentration of iron in fish measured after wet digestion of samples of freeze-dried and non-dried material

are all significant at the 1-per-cent level. Correlation coefficients for each fish species were not obtained because of the small sample numbers involved.

The results do not have unit slope, as would be expected from the assumption that any variation in results was solely caused by random error. The calculated slopes appear to have been strongly influenced by a number of samples with particularly high dried: non-dried ratios. Liver samples are shown to have notably higher metal content than whiteflesh samples.

Relationship between sample mass and non-dried: dried ratio

Plots of the non-dried:dried concentration ratio against original sample mass are shown in Figure 4 for each of the three elements. In all three cases the non-dried:dried ratio decreases as sample size increases. For zinc and iron, the correlation is significant at the 1-per-cent level, but for copper the relationship is not significant, probably because concentrations were near the limit of detection for this element. Such negative slopes could be explained by situations where contamination of small masses of non-dried samples (non-dried:dried ratios greater than 1) or incomplete dissolution during the oxidation step (i.e. loss of sample during filtering) of large masses of non-dried samples may have taken place.

The results have been plotted on Figure 5 as a frequency histogram, using a class interval of 0,1 for the non-dried:dried ratio and the reciprocal of the class boundaries for values greater than 1. For copper and zinc the results appear to be normally distributed, but for iron there is a distinctly bimodal distribution grouped around ratios of 0,7 and 1,7. If normal distribution is assumed, the range of ratios within which the population mean (μ) should fall (with 95-per-cent confidence limits) for a sample of given mean ($\bar{x}$) and variance ($\bar{S}^2$) may be calculated. For the three elements examined the ratios are:

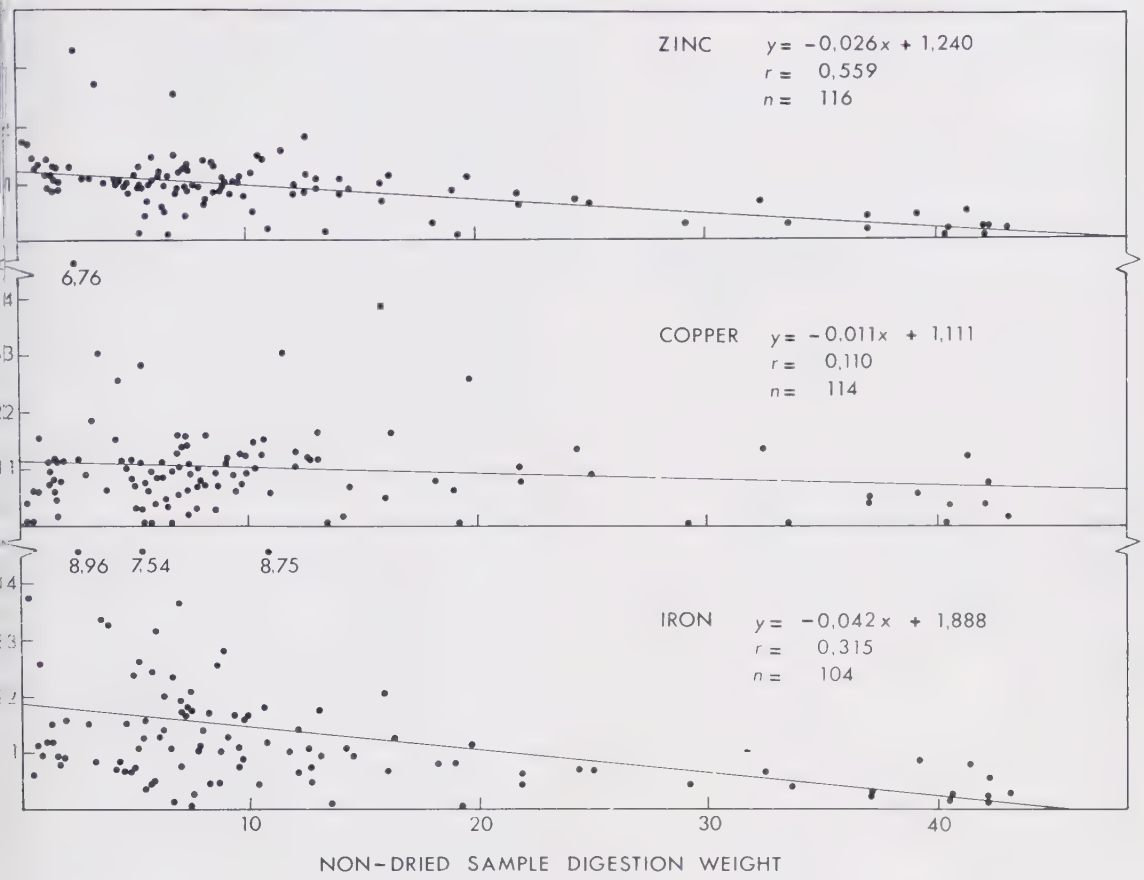


Fig. 4: Ratio of non-dried:dried concentrations plotted against non-dried sample mass

Table II: Metal content of hake at different masses of freeze-dried and non-freeze-dried samples

Sample mass (g)	Number of samples	Metal content ($\mu g \cdot g^{-1}$)					
		Copper		Iron		Zinc	
		dried	non-dried	dried	non-dried	dried	non-dried
		Freeze-dried					
2	5	0,69	0,14	17,15	3,50	13,23	2,70
		Non-dried					
5	2	1,57	0,32	48,31	9,86	17,39	3,55
10	2	0,98	0,20	17,34	3,54	12,84	2,62
15	2	0,88	0,18	12,98	2,65	11,17	2,28
20	2	0,69	0,14	8,43	1,72	9,85	2,01
25	2	0,69	0,14	6,57	1,34	11,47	2,34
30	2	0,78	0,16	6,52	1,33	11,56	2,36

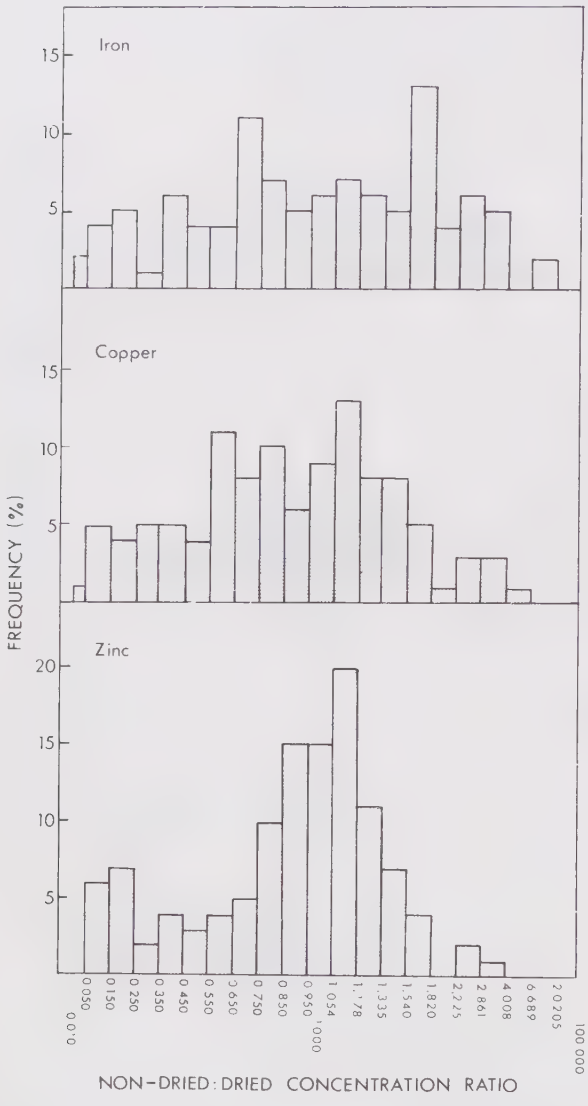


Fig. 5: Frequency of occurrence of non-dried:dried ratios for each element

Zinc	0,853	$\leqslant \mu \leqslant$	1,037
Copper	0,851	$\leqslant \mu \leqslant$	1,145
Iron	1,008	$\leqslant \mu \leqslant$	1,660

For copper and zinc the observed means of all results do fall in these areas, but in the case of iron the mean falls below this range, and the sample is therefore apparently weighted towards higher non-dried:dried ratios, undoubtedly because of bimodal distribution.

If the ratios obtained are further considered c a mass basis, there is a consistent bias towar lower non-dried:dried ratios with increasing samp size (Fig. 6). Therefore, sample size when performir wet digestion becomes important.

The effect of sample size on apparent met concentration was tested in another experimen A sample of hake (*Merluccius* sp.) was dissecte and the white muscle homogenized in a blende Aliquots of different mass were then digested a described previously and compared with analyse made on freeze-dried samples. The results ar shown in Table II, on both a dried and non-drie mass basis. In Table II, non-dried values of freez dried samples were calculated by dividing resul by 4,941, the ratio between wet and dried mass c the sample. Similarly, dried values for non-freez dried samples were calculated by multiplying b 4,941.

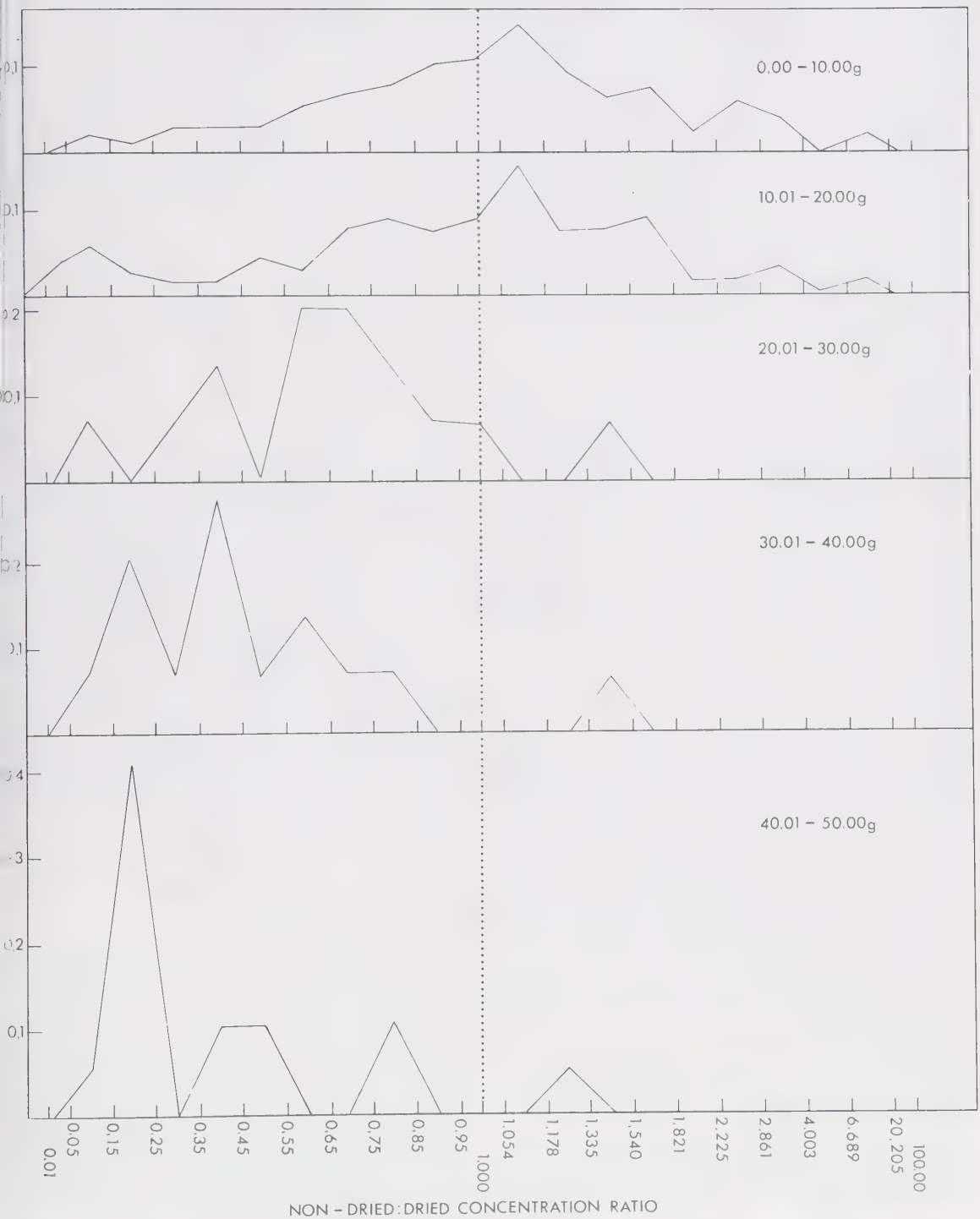
Copper concentrations were very low, in a cases being at the lower end of the range of thos previously reported for marine organisms fror the South African west coast (Fourie 1976). Som change in concentration was apparent at the smalles mass used, although this is probably not significan given the generally low concentrations which ar near the detection limit for the technique.

Both zinc and iron showed apparently lowe concentrations at larger sample mass. For bot elements, the concentration determined usin sample masses of 10 g corresponded most closel to that of the freeze-dried concentration. This i perhaps not surprising, considering that the non dried : freeze-dried mass ratio of the fish flesh used was 4,941; and 2,0 ± 0,1 g freeze-dried sampl was used. At larger masses the zinc content wa relatively constant and similar to previously reporte values (Fourie 1976). Iron concentrations, however declined with increase in sample mass.

DISCUSSION

The results from these experiments show that a real difference exists between the results of analyse performed after wet digestion of freeze-dried an non-dried material. The difference in concentratio was apparently caused by the differences in mas of samples taken for wet digestion, because all the samples analysed after freeze-drying had a mas of 2,0 ± 0,1 g material.

Figure 6 shows that the low non-dried:drie ratios occurred mainly with large initial wet (i.e not freeze-dried) sample masses. This factor ma



6 Relative frequency of occurrence of non-dried:dried concentration ratios plotted as a function of wet-digested sample mass (all metals) — points shown at centre of given class interval

have been the result of either or both of two possibilities. Firstly, for fish where the wet mass: dried mass ratio is about 5, as is the case here, a 40 g mass of fish will contain about 32 g water. This water would cause an immediate loss of oxidizing power in the acid, which could then fail to dissolve all the sample. Some metal ions would then remain embedded in the tissue and not be liberated into solution, resulting in a loss during the filtration step. Secondly, such an acid-water mixture would tend to form a constant-boiling solution (R. J. Watling, personal communication), and this could lead to the loss of an element as a volatile, probably organo-metallic, compound, For the elements studied, however, there was no evidence of the latter possibility having occurred.

It might also be thought that the variation in the volume of acid added would have an effect, particularly if any loss of volatile organo-metallics occurred during wet-ashing at temperatures below 95°C. It was found, however, that there was little apparent relationship between the sample mass chosen and the amount of acid needed to dissolve it. This was true not only when different species of fish were considered, but also when the volumes of acid required to dissolve the dried and non-dried samples of the same fish were compared. Table III reflects all the volumes of acid used, for both muscle and liver samples. Very little difference in the distribution of acid volumes required for the dissolution of either dried or non-dried samples can be seen.

The masses of sample corresponding to the 95-per-cent confidence limits around the mean can be determined from Figure 4. The three elements studied give the following non-dried sample masses as being in best agreement with the results obtained after freeze-drying: iron 14,15 g; copper 12,65 g; zinc 11,54 g. Therefore, for samples of fish muscle, a mass of between 10 and 15 g tissue should be used. For liver samples, smaller sample masses should undoubtedly be used because of the difficulty in dissolving this tissue when freeze-drying or oven-drying is not used. It would seem, therefore, that there is no real need for a drying step prior to acid dissolution provided that a sample in the correct mass range is taken.

This hypothesis was tested for sample masses of between 6 and 20 g. The cumulative distribution of the results from both dried and non-dried samples was plotted on cumulative probability paper (e.g., the zinc plot is reflected in Figure 7). A normal population would be expected to show a distribution

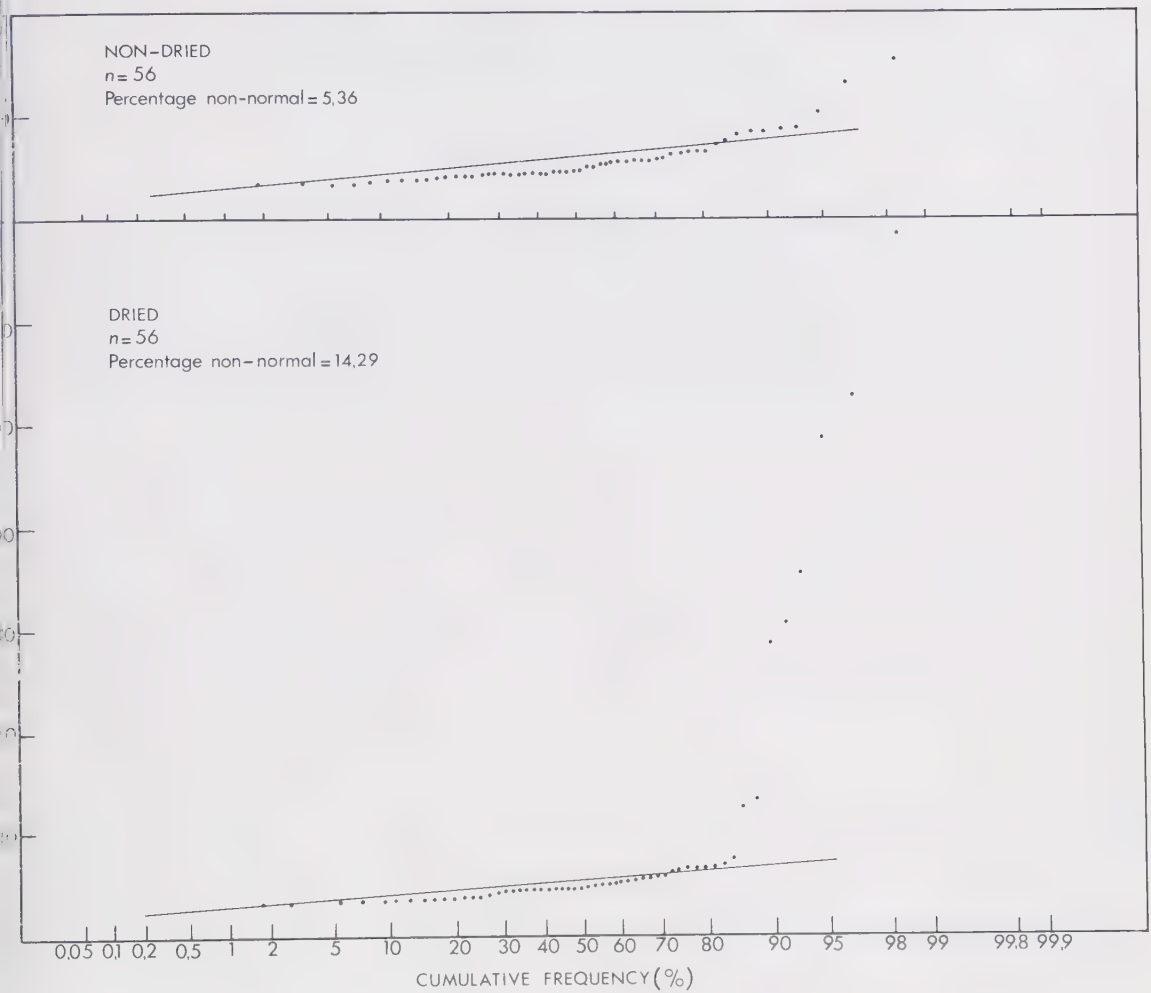
Table III: Volume of nitric acid required for digestion of different samples

Volume (mℓ)	Number of samples			
	Muscle		Liver	
	non-dried	dried	non-dried	dried
40	26	23	4	3
50	40	51	6	3
60	17	17	10	17
70	3	6	7	—
80	1	3	1	—
90	1	—	1	—
100	3	—	—	—
>100	—	1	5	—

which, when plotted in this manner, yields a straight line graph. Deviations from this straight line would indicate non-normality and the occurrence of more than one population. The results plotted in Figure 7 show that the majority of the samples came from a normal population with a small number of random high values. If it is assumed that these high values are indicative of contamination, it would appear that the use of a drying step contributes to an increased error in the results, as evinced by the higher proportion of non-normal samples (e.g., for zinc 14 per cent when freeze-dried, 5 per cent when not). Similar results were obtained for both copper and iron, where the percentages of non-normal samples were 40 per cent and 26 per cent respectively for the dried samples, compared with 13 per cent and 6 per cent for the non-dried samples.

CONCLUSIONS

The analysis of samples of 11 species of fish from South African coastal waters showed that the variation in metal levels obtained by analysis after wet ashing of freeze-dried and non-dried samples was strongly related to variations in sample size. Liver tissue required more acid per unit mass than muscle tissue because of its higher oil content. It is concluded that freeze-drying is not a necessary step in the analytical procedure, and it is recommended that between 10 and 15 g of muscle be used for direct wet digestion.


NON-DRIED
n = 56
Percentage non-normal = 5,36
DRIED
n = 56
Percentage non-normal = 14,29
0,05 0,1 0,2 0,5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99,8 99,9
CUMULATIVE FREQUENCY (%)

7: Cumulative probability distribution of zinc concentrations obtained for sample masses between 6 and 20 g — the straight line shows the extent of the normal population

ACKNOWLEDGEMENTS

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DISTRIBUTION, AVAILABILITY AND MOVEMENTS OF ROUND HERRING *ETRUMEUS TERES* OFF SOUTH AFRICA, 1964—1976

R. J. M. CRAWFORD

Since 1966, the first year in which all species in South Africa's purse-seine fishery were permitted to be caught with small-meshed (12,7-mm) nets, round herring *Etrumeus teres* has been a small but valuable and fairly regular contributor to the combined mixed-species landings. The highest round-herring catch, almost 32 000 tons, was recorded in 1967. The species generally shoals by size. Some individuals one and two years old attain sexual maturity, but all are reproductively active when they are five years old. The greater part of the population appears to be confined to the region south of latitude 31°S and west of Cape Agulhas. Most catches are made inside the 200-m bottom contour, but aerial observations indicate that the species extends considerably farther off shore. Nought-year-olds recruit to the fishery from mid autumn, whereas availability of one-year-olds increases after February, but declines sharply after May. Both these age categories show some movement towards the south. Catch rates of adults are highest in summer and autumn, after which an off-shore spawning migration probably takes place.

Sedert 1966, die eerste jaar waarin toegelaat is dat al die spesies in die Suid-Afrikaanse beursnetvissery met fynmaasnette (12,7 mm) gevang word, het rooioog *Etrumeus teres* 'n klein maar waardevolle en taamlik gereelde deel uitgemaak van die gesamentlike veelsoortige vangste. Die grootste rooioogvangs, byna 32 000 ton, is in 1967 opgeteken. Saamskoling by die spesie geskied gewoonlik volgens grootte. Enkeles bereik geslagsrypheid tussen die ouderdom van een en twee jaar, maar almal is aan die voortplant wanneer hulle vyf jaar oud is. Die merendeel van die stapel is blykbaar in die gebied suid van die breedte 31°S en wes van Kaap Agulhas gekonsentreer. Vangste word meesal binne die 200-meter-bodemkontoer gedoen, maar waarnemings uit die lug dui daarop dat die spesie se verspreiding heelwat verder van die kus af uitstrek. Nul jaar oue rekrute tree van die middel van die herfs af tot die vissery toe, terwyl die beskikbaarheid van jaaroud rekrute ná Februarie toeneem, maar ná Meimaand skerp afneem. By albei hierdie ouderdomskategorieë is daar blyke van 'n beweging suidwaarts. Die vangkoerse van geslagsrypes is die hoogste in die somer en herfs, waarna daar vermoedelik 'n migrasie see in plaasvind om kuit te skiet.

)fficial records indicate that commercial landings round herring *Etrumeus teres* prior to 1964 re minimal, except in 1959 (Table I). Though may in part have been the result of misidentifi-on of catches (Geldenhuys 1978), the grounds oured by fully recruited age groups were atively lightly exploited in these earlier years awford *et al.* 1978). More recently, however, species has become a small but valuable R900 000 in 1976 after processing) and fairly ular contributor to the combined purse-seine dings, annual catches generally fluctuating be-een 10 000 and 35 000 metric tons. The catch in 74 was unusually low, but in this year availability anchovy *Engraulis capensis* was good, catch otas were quickly filled and the season was ought to an early close.

Growth of round herring has been investigated Geldenhuys (1978), but little is known of the ecies' distribution or of its seasonal changes in ailability to the purse-seine fleet — factors which uld prove significant in any future attempts to rect fishing operations. This report endeavours elucidate these patterns through the analysis of

Table I: Landings of round herring and their contribution to the total South African purse-seine catch, 1958—1976*

Year	Landings (metric tons)	Proportion of total combined landings (%)
1958	802	0,3
1959	2 553	0,8
1960	88	0,0
1961	130	0,0
1962	110	0,0
1963	197	0,0
1964	2 718	0,6
1965	8 243	1,7
1966	15 432	4,3
1967	31 961	6,3
1968	30 298	8,2
1969	23 301	6,6
1970	23 694	6,6
1971	21 644	6,7
1972	20 567	4,7
1973	28 657	6,3
1974	1 276	0,3
1975	23 551	5,8
1976	11 709	2,9

* No landings of round herrings were recorded prior to 1958

catch and sample information collected over the period 1964—1976.

DISTRIBUTION OF COMMERCIAL PURSE-SEINE CATCHES

Monthly distribution patterns of commercial catches of round herring for the period 1964—1976 were derived from catch statistics submitted by skippers of purse-seine vessels in a similar manner to that described for the pilchard *Sardinops ocellata* population (Crawford 1981a). The results are presented in chart form in the Appendix. Areas in which no fishing was conducted are identified to assist in overall interpretation of the charts, and catch rates are shown to depict regional differences in the density of fish.

Examination of the length compositions of round herring in 120 purse-seine catches made between 1972 and 1976 revealed that, in South African waters, round herring from any one shoal seldom differ in caudal length by more than 5,5 — 6,5 cm (Fig. 1), a slightly larger variation than exists in pilchard and anchovy shoals (Crawford 1981a, b). The modal length of fish caught in known areas has been included on the distribution charts whenever this information was available from field observations, to give some indication of geographical and seasonal differences in the size of fish encountered.

Geldenhuys (1978) investigated reproductive activity in round herring collected between 1965 and 1971. He found that 50 per cent of the fish examined were mature at a caudal length of 17,0 cm and 100 per cent at a length of 22,0 cm. Unfortunately, no indication was given of sample size or of the smallest length at which active gonads were encountered. In addition he assumed that spawning took place throughout the year. P. A. Shelton (Sea Fisheries Institute, personal communication) is of the opinion that, although eggs may be produced in limited quantities at any time, a distinct spring-summer spawning season, similar to that of pilchard and anchovy, may nevertheless be distinguished. This conforms to trends in the availability of nought-year-old round herring, which will be discussed later.

Size at maturity was therefore re-examined using only material that had been collected during the summers of 1973—1977. No samples were available for spring. Gonads of 1 399 individuals were classified according to the method adopted by Davies (1956) and the caudal lengths at first, 50-

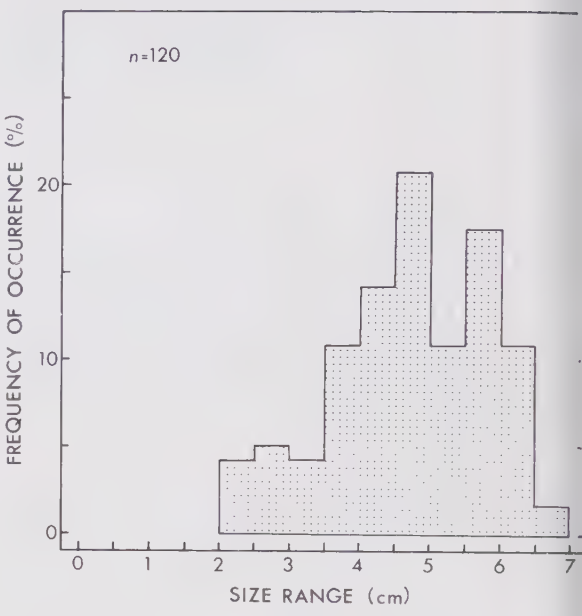


Fig. 1: Frequency of occurrence of size ranges (cauda length) of round herring sampled from individual commercial purse-seine catches

per-cent and 100-per-cent maturity were found to be about 12,0 cm (one and two years old), 15,0 cm (two and three years old) and 20,5 cm (four and five years old) respectively (Table II). These results are not substantially different from those of Geldenhuys (1978). For charting purposes, nought-year-old fish were considered to be juveniles and have been illustrated in different shading from that used for all older age groups. The technique therefore highlights the distribution of recruit year-classes.

As in the cases of the pilchard and anchovy populations (Crawford 1981a, b), the results indicate that the bulk of the round-herring catches are made inside the 200-m bottom contour, except where this contour approaches the mainland in the vicinities of Cape Columbine and Cape Point. Off-shore catches of nought-year-olds were recorded west of Cape Town in January 1968; of one-year-olds north-west of Cape Columbine in January 1970; of two-year-olds between Dassen Island and Cape Town in February 1970; of four-year-olds north-west of Cape Columbine in February 1972 and west of Cape Town in February 1969 and January 1972; and of five-year-olds west of Cape Town in March 1969.

Round herring have been encountered in South

e II: The relationship between gonad activity and audal length in round herring, 1973—1977 (only summer data were considered)

udal gth m)	Stage of activity*								Total
	0	1	2	3	4	5	6	7	
5.0	—	1	—	—	—	—	—	—	1
5.5	—	1	—	—	—	—	—	—	1
6.0	—	—	—	—	—	—	—	—	—
6.5	—	13	—	—	—	—	—	—	13
7.0	—	57	—	—	—	—	—	—	57
7.5	—	87	—	—	—	—	—	—	87
8.0	—	56	—	—	—	—	—	—	56
8.5	—	29	—	—	—	—	—	—	29
9.0	—	20	—	—	—	—	—	—	20
9.5	—	10	—	—	—	—	—	—	10
0.0	—	5	—	—	—	—	—	—	5
0.5	—	8	—	—	—	—	—	—	8
1.0	—	3	—	—	—	—	—	—	3
1.5	—	2	—	—		—	—	—	2
2.0	—	7	—	5	—	—	—	—	12
2.5	—	13	—	5	—	—	—	—	18
3.0	—	4	—	5	—	—	—	—	9
3.5	—	4	—	2	—	—	—	—	6
4.0	—	4	—	12	—	—	—	—	16
4.5	—	16	—	8	—	—	—	—	24
5.0	—	26	—	25	—	—	—	—	51
5.5	—	38	—	37	—	—	—	—	75
6.0	—	31	—	50	—	2	—	—	83
6.5	—	27	—	60	—	1	—	—	88
7.0	—	22	—	74	—	3	—	—	99
7.5	—	28	—	88	—	6	—	—	122
8.0	—	13	—	107	—	11	—	—	131
8.5	—	11	—	90	—	11	—	—	112
9.0	—	4	—	72	—	21	—	—	97
9.5	—	1	—	38	—	15	—	—	54
0.0	—	1	—	29	—	8	—	—	38
0.5	—	—	—	12	—	12	—	—	24
1.0	—	—	—	10	—	12	—	—	23
1.5	—	1	—	3	—	9	—	—	12
2.0	—	—	—	—	—	6	—	—	6
2.5	—	1	—	1	—	4	—	—	6
3.0	—	1	—	—	—	—	—	—	1
tal	—	545	—	733	—	121	—	—	1 399

lassification according to Davies (1956)

rican waters as far north as 30°S where, in May 65, some four-year-old fish were caught. A few ditional records exist of catches made north of °S (nought-year-olds in April 1968, January and ne 1969 and May 1973; one-year-olds in May d June 1971; two-year-olds in February 1974). owever, the shoals have usually been small and e catch rates low. Catches east of Cape Agulhas ve also been infrequent (one-year-olds in June 75; two-year-olds in February and April 1970, ril 1971 and March 1976; three-year-olds in March 1973; four-year-olds in March 1967). Again they have generally resulted in low catch rates. The greater part of the round-herring population, therefore, appears to be confined to the region south of 31°S and west of Cape Agulhas.

Additional information on the distribution of the species is available from aerial observations made between 9 June and 16 October 1973. During this period, some 310 hours were spent in the air, mainly at night, searching for patches of fish. The area covered is illustrated in Figure 2. Off southern Africa, the Benguela Current system contains many species of phytoplankton which are luminescent and sufficiently numerous to clearly outline the shape of fish shoals moving through them at night (Cram 1974). Round herring are frequently activated to movement by the noise of an aircraft's engines, often lighting up the sea in a brilliant and characteristic fashion, whereas they do not always respond to flashing spotlights.

Sightings of round-herring shoals during the period of aerial observation are illustrated in Figure 3. It is noteworthy that most of the observations were made more than 15 km from the mainland and that a number of shoals were located outside the 200-m bottom contour, suggesting that the distribution of the commercial catches of this species is influenced to a large extent by the preference of skippers to remain within sight of the coast. West of Cape Columbine and west of Cape Town, shoals were encountered more than 100 km out to sea. The majority of observations were made on the Saldanha Bay and Hout Bay grounds. An exceptionally large patch of round herring was seen on the night of 18 June, stretching discontinuously for more than 80 km between 33°53′ S, 17°05′ E and 33°57′ S, 18°00′ E.

AVAILABILITY, ABUNDANCE AND MOVEMENTS

Seasonal patterns of availability and distribution were quantified by dividing the fishing area into six grounds (Fig. 2), chosen to correspond with the major environmental regions of the South-Western Cape (Crawford *et al.* 1980). Most catches are made within 50 km of the mainland (Appendix) and the grounds are therefore of approximately equal size except for the extensive, but relatively lightly exploited, Namaqua area.

Monthly indices of availability and of the relative abundance of fish that could be expected to be present on each of the six grounds were determined

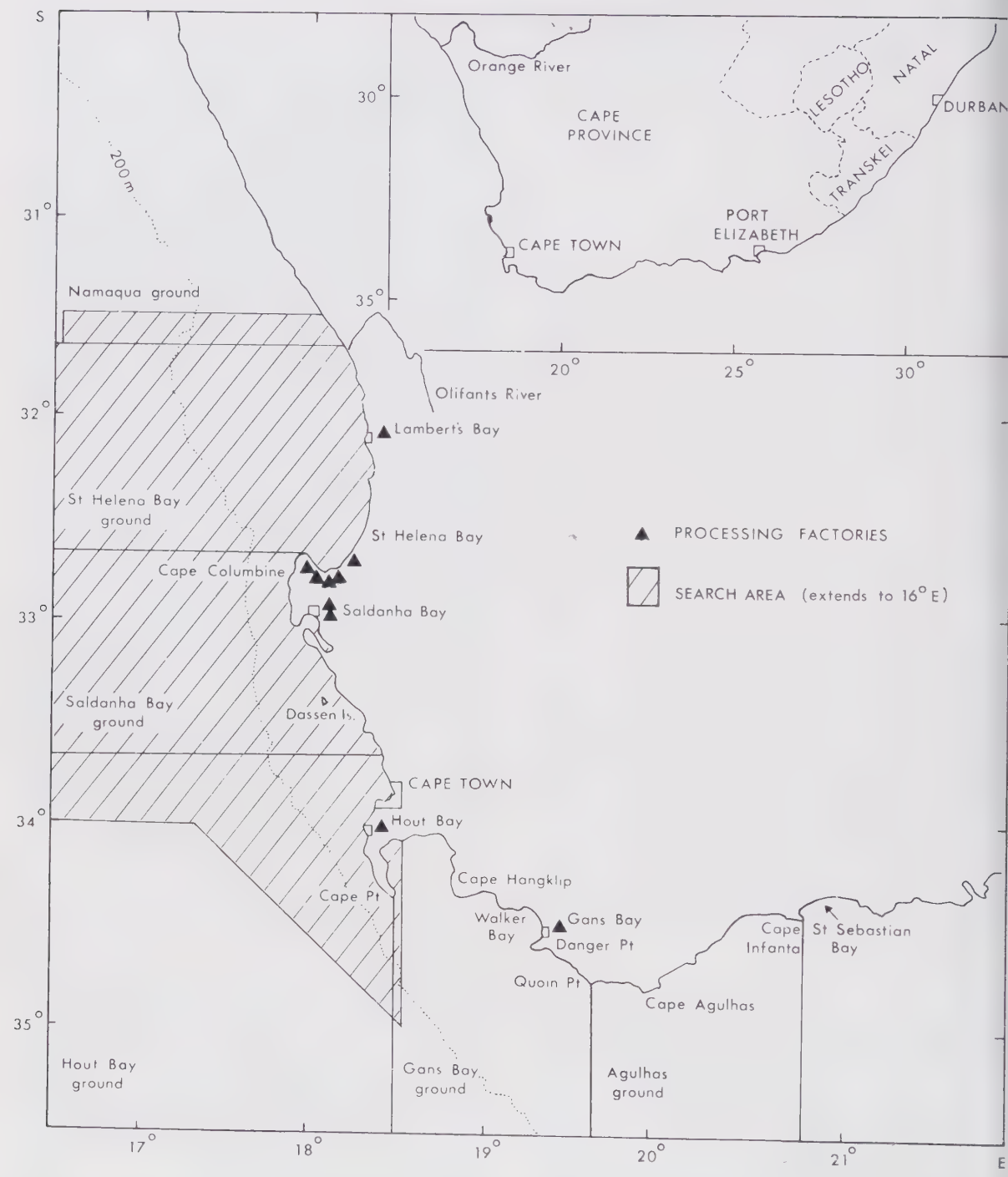
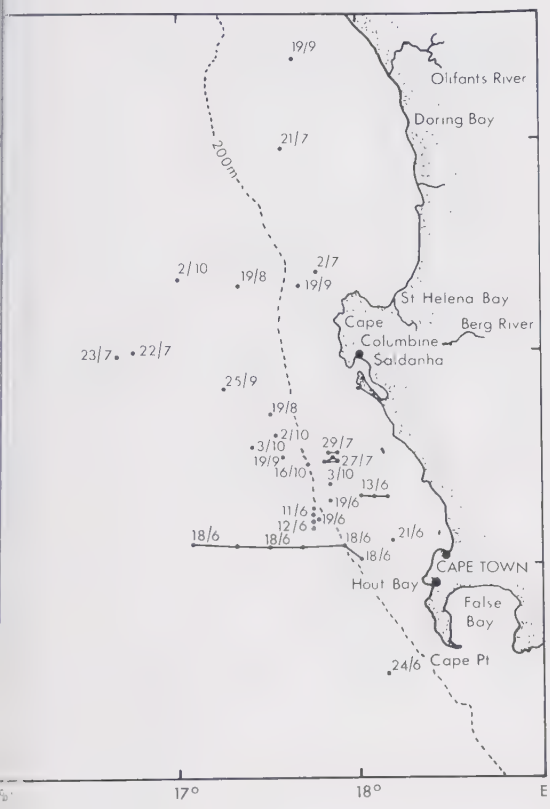


Fig. 2: The main South African purse-seine fishing grounds, showing the area searched from the air during 1973 and the localities of the processing factories operative in 1976 — the Namaqua ground extends north to the Orange River (inset)



3: Sightings of round-herring shoals from the air off South Africa's west coast between 10 June and 3 October 1973 — dates are shown

manner analogous to that described for the hard population (Crawford 1981a). The years 4 — 1976 were used for fish aged two and der, but only 1966—1976 were considered for ught- and one-year-olds. Fishing for round herring th the 12,7-mm net was not permitted in earlier ars and, from the age composition of commercial ndings (Fig. 4), it is suggested that these young sh were not fully selected in 1964 and 1965. alues were not calculated for October, November December, the season being closed for round-rring catching during these months in every ar.

The resulting estimates of availability and relative undance, expressed as percentages of the maxima, pear in Figures 5 and 6. Mortality is expected to fluence trends exhibited by fully recruited age asses (one-year-olds and two- to five-year-olds), t unrealistically high values ($Z = 5,3$ and 7,0 for ch group respectively) would be required to account for the observed decline in availability. No reliable coefficient of natural mortality is available for round herring in South African waters, but it is thought to be less than that calculated for anchovy (0,8), a shorter-lived species (Crawford 1980). Centurier-Harris *et al.* (1977) found that, between 1964 and 1976, round-herring fishing mortality ranged from 0,03 to 1,58 (mean 0,54). Undoubtedly fish movements and behaviour also exert a considerable influence on patterns of availability and abundance. These will be dealt with in greater detail when considering the various age components of the population.

Nought-year-old fish

Availability of nought-year-old round herring is at a moderate level in January, but falls sharply during February and March before rising again in April. Catch rates are highest in September (Fig. 5). The pattern is therefore similar to that of pilchard (Crawford 1981a), although recruitment of round herring possibly commences one month earlier. As do young pilchard and anchovy (Crawford 1981b), young round herring appear to move south towards the end of winter or at the beginning of spring. Catch rates on the Namaqua ground decline after June, whereas those in the Gans Bay region increase markedly in August and September (Fig. 6).

The trend in availability is fairly regular (see Appendix), particularly for the years 1967, 1968, 1969, 1970, 1973, 1976 and possibly 1966. Moreover, although in 1971, 1972 and 1975 there were no landings of juveniles in January, catch rates improved during the latter part of the season, as in the other years studied. In 1964 and 1965, nought-year-old round herring were not fully selected by the fishing gear in use (Fig. 4) and, as demonstrated for pilchard (Crawford *et al.* 1980), their apparent scarcity in 1974 may have resulted from an early closure of the fishing season.

A southward expansion in the distribution of this age class during winter is apparent for a number of years (June 1967, June — August 1970, June 1971, June 1972, May 1975, August 1976). In addition there was a noticeable build-up in the number of catches made south of Cape Columbine in August 1966.

One-year-old fish

Availability of one-year-old round herring increases after February, probably as a result of

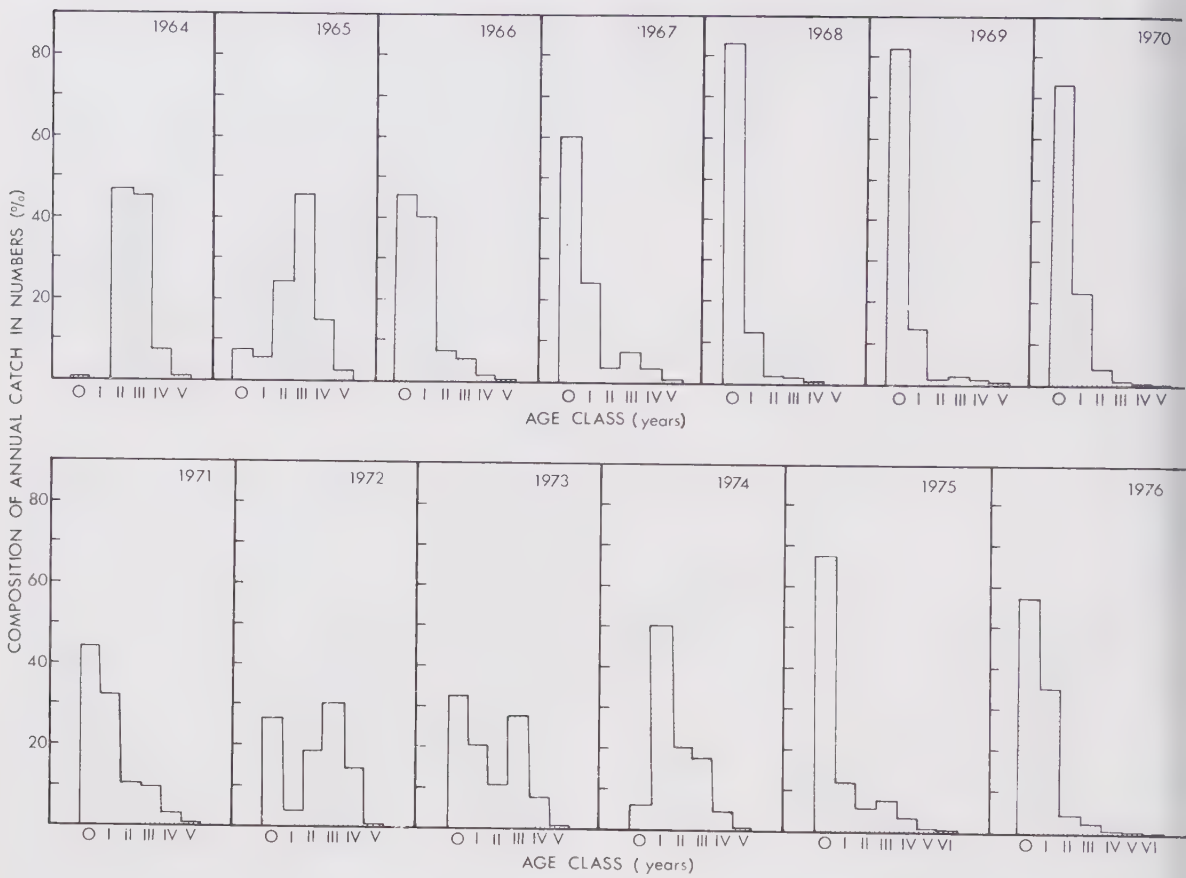


Fig. 4: Age composition of South African round-herring landings, 1964 — 1976 (data after Crawford *et al.* [1978])

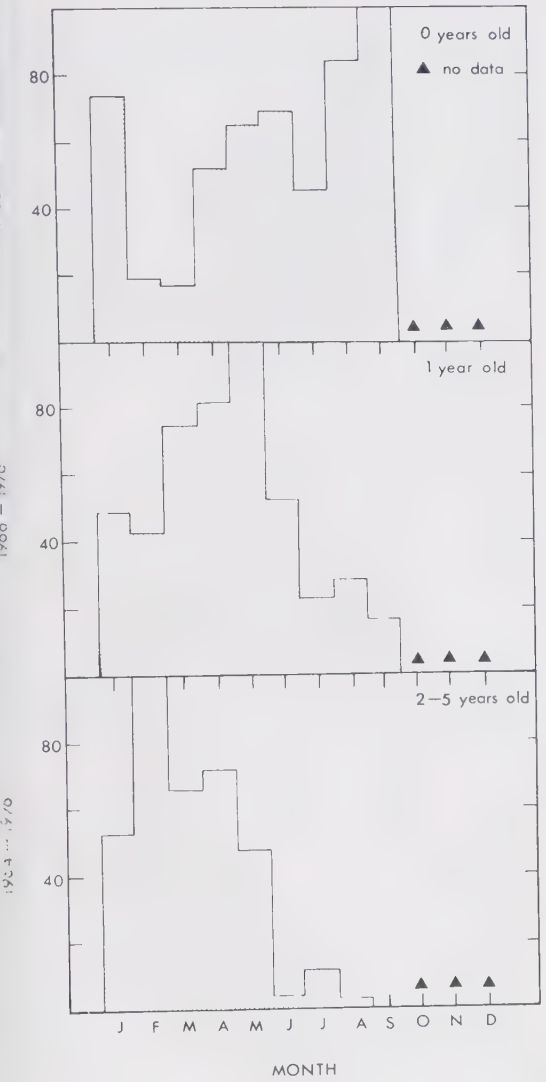
large numbers of nought-year-old fish entering their second year of life at this time, and reaches its highest level in May. Thereafter there is a sharp decline, with generally poor catch rates being experienced at the end of winter (Fig. 5). Again the pattern is almost identical to that of the pilchard population (Crawford 1981a) and the analogy is carried one step further by a southward shift in abundance during autumn (Fig. 6). Unlike the pilchard, however, a substantial proportion of this component of the round-herring stock is caught in the Gans Bay area, whereas smaller returns are made on the Namaqua ground. The round herring therefore assumes a relatively more southerly distribution.

One-year-old round herring were not fully selected in 1964 and 1965, but fairly good catches were recorded during the autumns of 1966, 1967, 1969, 1971, 1972, 1973 and 1976 and lesser quantities in 1968, 1970, 1974 and 1975 (Appendix).

There was a clear migration to the south in 1967. One-year-olds were caught off Lambert's Bay in January and February, between the Olifants River and Cape Columbine in March, from the Olifants River to Saldanha Bay and off Hout Bay in April and from Dassen Island to Walker Bay in May. A similar movement is also apparent for 1966 (March/April and May/June), 1968 (March — May), 1969 (April — June), 1970 (February — April), 1971 (April/May), 1972 (March/April), 1973 (March/April) and 1976 (April/May).

Two- to five-year-old fish

Preliminary analysis revealed that the behaviour



. 5: Age-specific monthly availability indices for round herring

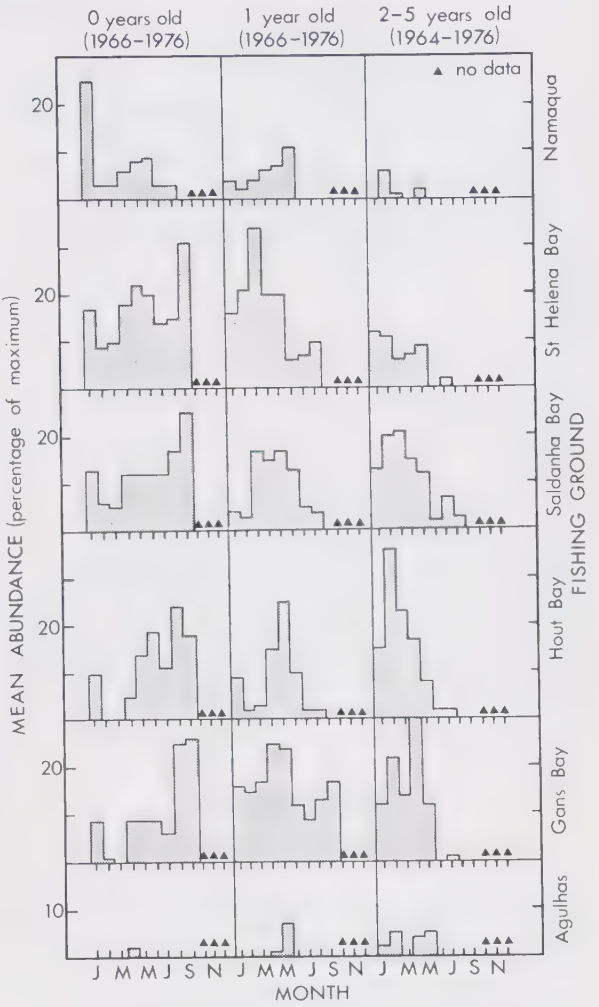


Fig. 6: Age-specific monthly abundance indices for round herring for six fishing grounds

round herring aged between two and five years as similar and fish of these ages are therefore nsidered together. Similar to two- to four-year-d pilchard and the adult anchovy age groups, ey are most abundant in summer, and catch tes decline with the advent of winter (Fig. 5). lthough mortality can only partially account for e observed decrease in availability, no distinct nd regular migration off the fishing grounds in a ngshore direction could be detected. It is possible, however, that adults move off shore at this time. Between June and October 1973, aerial observations indicated that most shoals were located farther than 15 km from the mainland (Fig. 3), and the initial results of a recent plankton survey (P.A. Shelton, personal communication) suggest that most spawning takes place off shore.

Adult round herring occur most commonly on the Saldanha Bay, Hout Bay and Gans Bay grounds (Fig. 6). By contrast, two- to four-year-old pilchard favour the Gans Bay and Agulhas areas and may be distributed even further east, although those aged five or six occur predominantly on the West

Table III: Months in which catch rates of two- to five-year-old round herring greater than 10 metric tons per standard-boat-day have been recorded

Month	Season
January	1966, 1972, 1973, 1975
February	1965, 1966, 1969, 1970, 1971, 1972, 1973, 1975
March	1967, 1969, 1970, 1971, 1973, 1974, 1976
April	1966, 1967, 1968, 1971, 1972, 1975
May	1964, 1975
June	1968
July	1976
August	1968
September	--
October	—
November	—
December	—

Coast (Crawford 1981a).

The charts in the Appendix reflect the relative abundance of round-herring adults during summer or autumn of every year with the possible exception of 1974. Catch rates greater than 10 metric tons per standard-boat-day were often achieved in these seasons, but were infrequent later in the year (Table III).

DISCUSSION

Round herring have relatively large scales, which they shed readily when disturbed. This frequently leads to clogged meshes and a net that is both difficult to purse and that will later require considerable time and effort to clean. Fishermen, therefore, generally avoid this species when it can be recognized and when other fish are plentiful in the vicinity. Therefore, trends demonstrated in this report will be subject to an element of bias, although the frequent repetition of seasonal patterns throughout the study period leads to the belief that the behaviour of the round-herring stock is adequately described.

The distributions, availabilities and migrations of both nought- and one-year-old round herring are similar to those exhibited by the corresponding pilchard age groups, suggesting that those environmental factors which determine the behaviour of the latter (Crawford *et al.* 1980) are applicable also to the round herring during its first two years of life. As a consequence of this fact, young round herring are frequently found in mixed shoals with either pilchard or anchovy. Of all juvenile round herring landed during the thirteen-year period (1964-1976), 98 per cent were combined with other species in mixed catches.

Older round herring tend to assume a more northerly, and possibly off-shore, distribution than their pilchard counterparts. This distribution may be linked to spawning, because the densest egg concentrations are encountered between Lambert's Bay and Cape Agulhas in off-shore water (P.A. Shelton, personal communication). O'Toole and King (1974) have demonstrated that the rate of development of round-herring eggs increases exponentially with temperature over the range 11,5 — 20,5°C, but they identified no lower lethal limit. Lower lethal limits of 13,0 and 14,0°C were recorded for pilchard and anchovy respectively in southern African waters (King *et al.* 1978). Round-herring eggs are therefore considerably more tolerant of cold water masses than are those of the other two species, which may explain the presence of round-herring eggs in regions that are subject to the influence of cool upwelling plumes. They are also spawned in warmer water east of Cape Point (P. A. Shelton, personal communication). Because the older round-herring age groups are found on the Saldanha Bay and Hout Bay grounds, the species often co-occurs with mackerel *Scomber japonicus* in mixed shoals (Geldenhuys 1978). A total of 15 per cent of the round herring landed between 1964 and 1976 was from such shoals.

In future years the round-herring population may attract a greater proportion of the fishing effort. The past two decades have witnessed the sequential depletion of some traditional resources: those of horse mackerel *Trachurus trachurus*, of pilchard aged five and older, and of mackerel (Newman and Crawford 1980). Also, the remaining age components of the pilchard and anchovy stocks are being subjected to increasingly high levels of exploitation and are in danger of being overfished (Crawford 1981c).

Because of the preference of purse-seine fishermen for other species in earlier years, it is possible that the round-herring population may have been underexploited and could have sustained higher harvests. However, two factors make this possibility rather unlikely. Firstly, the tendency of juvenile round herring to shoal with other species has made it difficult for skippers of purse-seiners to deliberately avoid them. Secondly, virtual population estimates of round-herring recruitment are considerably less than those for pilchard and anchovy

e IV: Virtual population estimates of pilchard, anchovy nd round-herring recruitment, 1964—1976 (from Centurier-Harris *et al.* 1977)

Year	Numbers ($\times 10^{-10}$)		
	Pilchard	Anchovy	Round herring
1964	0,32	3,91	0,13
1965	0,32	3,30	0,15
1966	0,52	5,66	0,20
1967	1,03	6,80	0,32
1968	1,03	4,98	0,74
1969	0,62	5,56	0,63
1970	0,62	6,10	0,53
1971	0,89	4,55	0,13
1972	0,43	4,32	0,14
1973	1,12	9,01	0,07
1974	1,81	5,39	0,06
1975	1,39	7,58	0,39
1976	0,01	5,60	0,19
Mean 964—1976	0,78	5,59	0,28

ble IV). Therefore, it would seem unwise at stage to pin too much hope on greatly improved ches of round herring in forthcoming seasons.

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his study was supported by a grant from the neries Development Corporation of South ca Ltd. I am grateful to Professor J. G. Field the University of Cape Town, and to my eagues Dr G. G. Newman and Messrs A. I. L. ne and R. A. Cruickshank for commenting on draft manuscript. I thank Messrs F. Kriel and H. L. Wingate for conducting much necessary dwork and assisting with the preliminary data nipulation, and all other technicians who were olved to a greater or lesser degree. I also thank r P. A. Shelton for making available information round-herring spawning.

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APPENDIX

ROUND-HERRING CATCH LOCATIONS 1964—1976

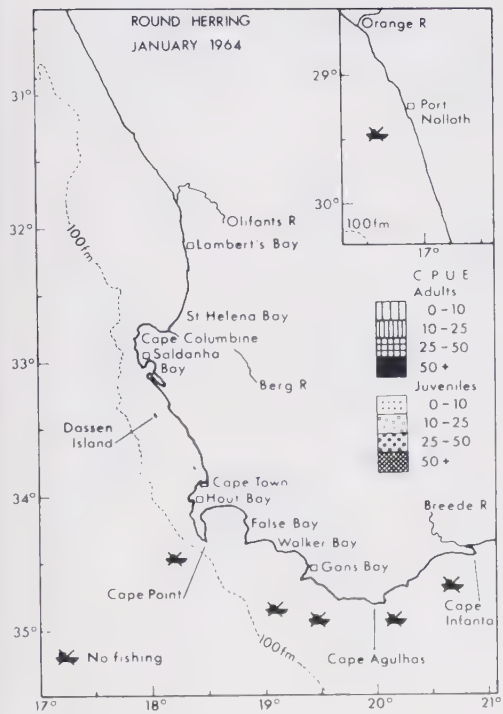
From 1969 to 1976 no maps are shown for September—December inclusive, because exploitation of round herring was prohibited during these months.

Levels of catch per unit effort (C.P.U.E.) are indicated as metric tons per standard-boat-day.

Modal caudal lengths (cm) of fish from different areas are shown adjacent to catch locations. Growth rates may be expected to vary between seasons, but some indication of age is provided by the von Bertalanffy growth equation calculated by Gelden-huys (1978):

Age (years)	Predicted caudal length (cm)
1	8,4
2	13,5
3	17,1
4	19,7
5	21,5
6	22,8
7	23,8
L_{oo}	26,2

Areas in which there was no deployment of fishing effort are shown.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Orange R
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
100fm
No fishing
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Juveniles
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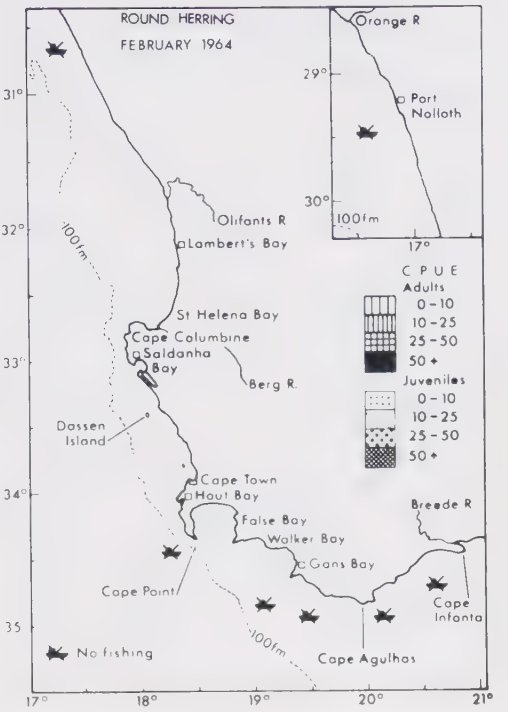
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False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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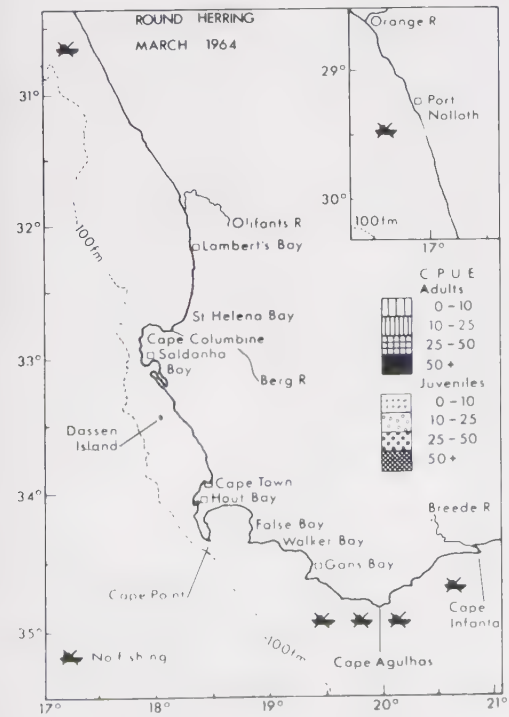
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Gans Bay
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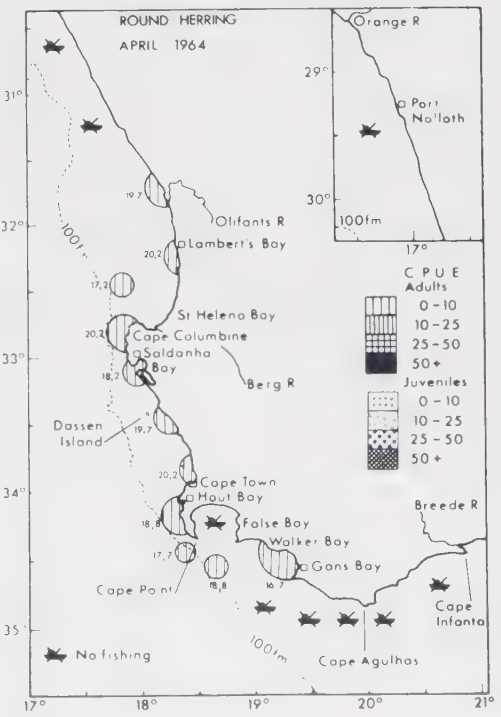
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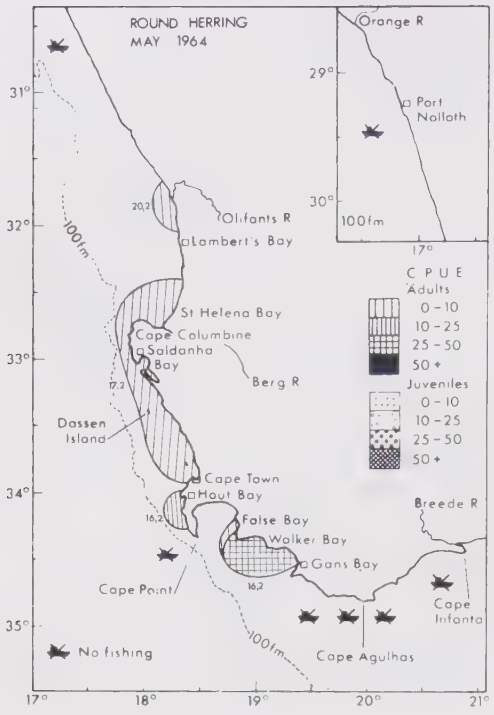
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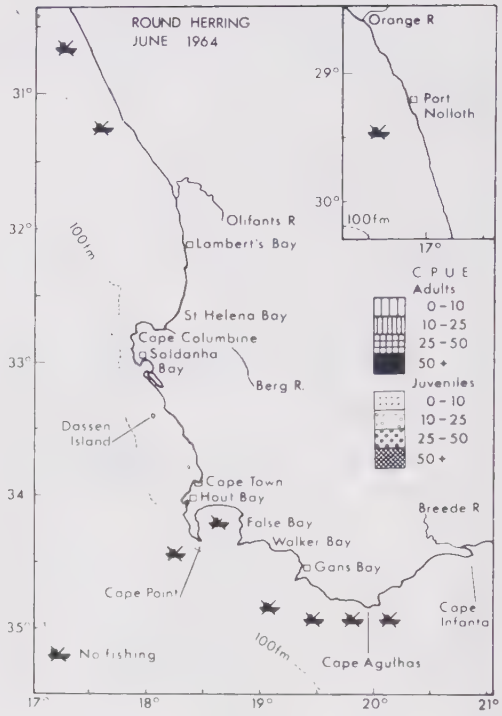
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Walker Bay
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Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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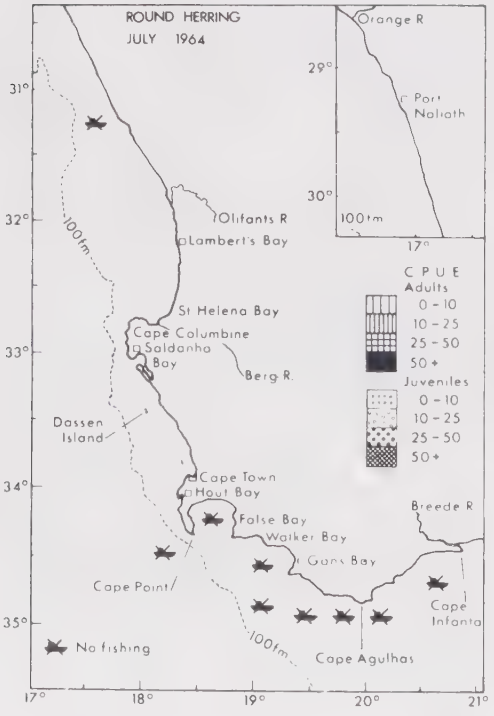
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Cape Agulhas
No fishing
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Adults
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Juveniles
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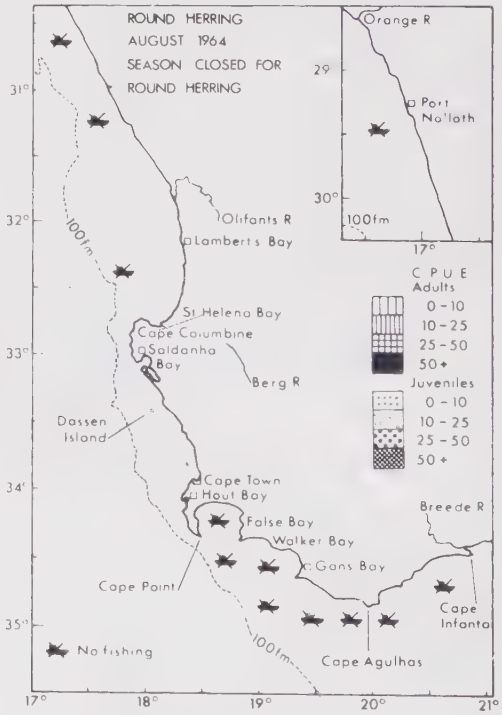
25 - 50
50 +


ROUND HERRING
AUGUST 1964
SEASON CLOSED FOR
ROUND HERRING
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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Juveniles
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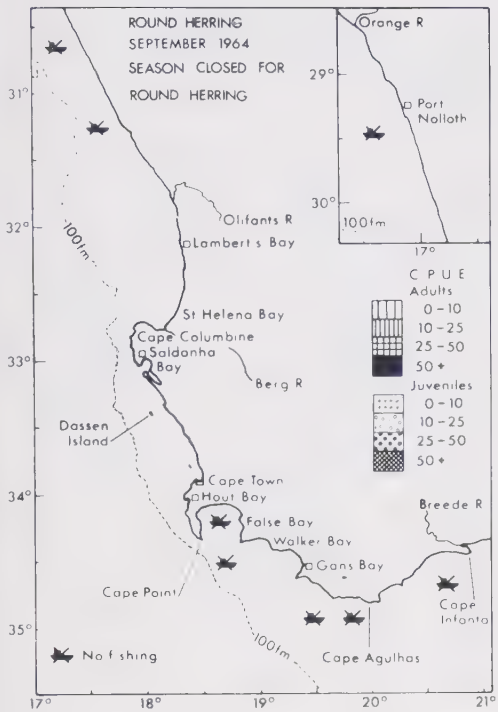
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Adults
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Juveniles
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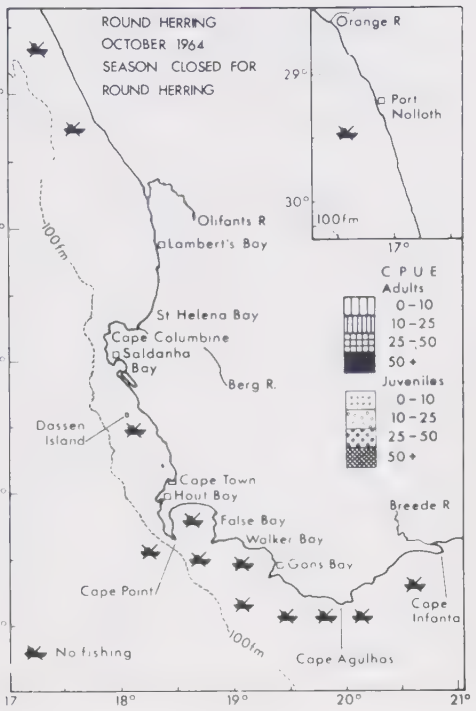
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OCTOBER 1964
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Port Nolloth
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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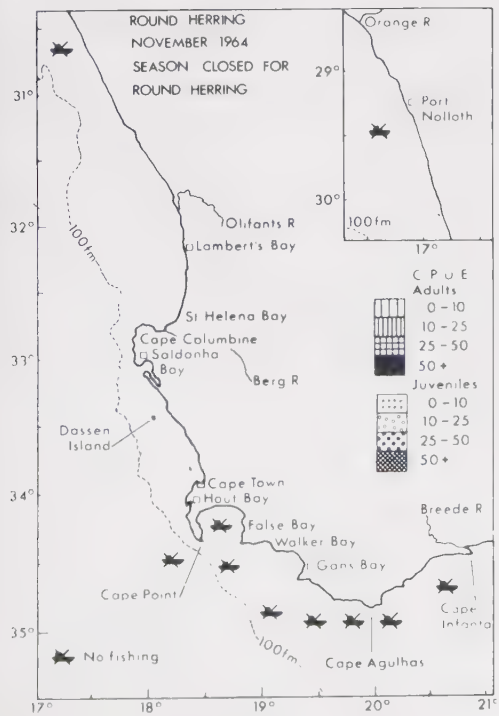
ROUND HERRING
NOVEMBER 1964
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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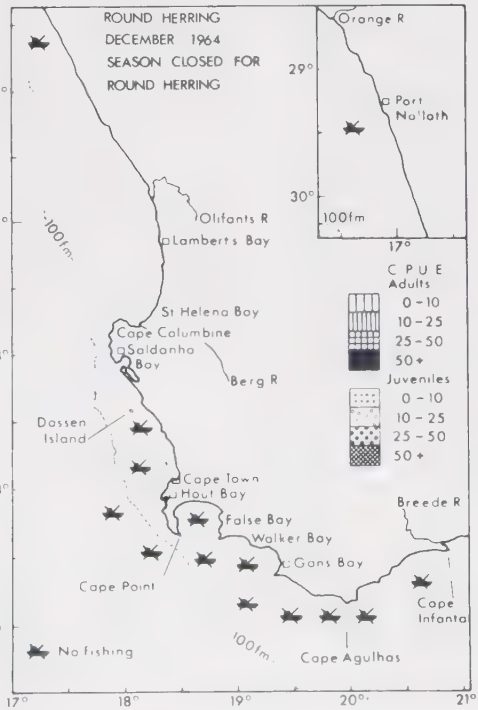
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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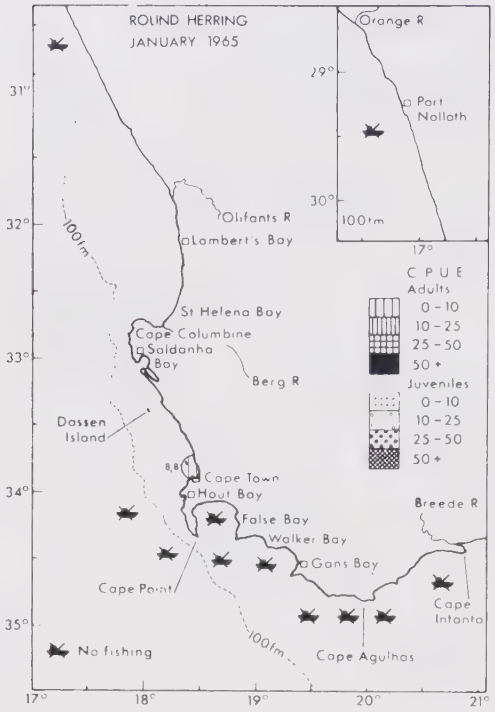
ROUND HERRING
JANUARY 1965
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Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Dassen Island
Cape Town
Hout Bay
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Cape Infanta
Cape Agulhas
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Juveniles
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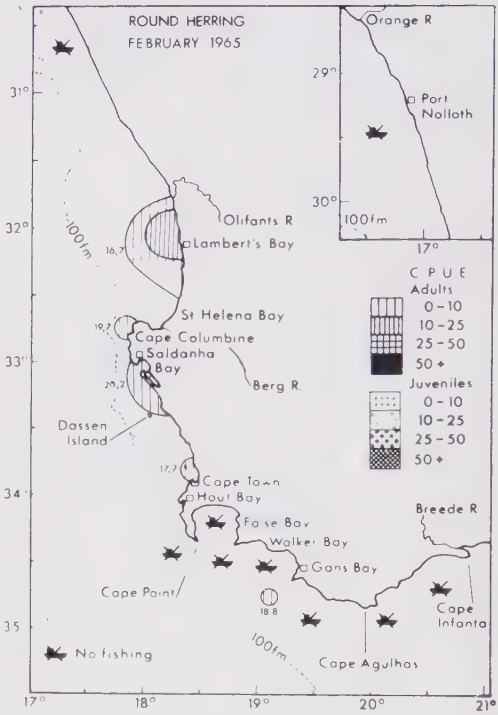
ROUND HERRING
FEBRUARY 1965
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
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Cape Agulhas
No fishing
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Adults
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Juveniles
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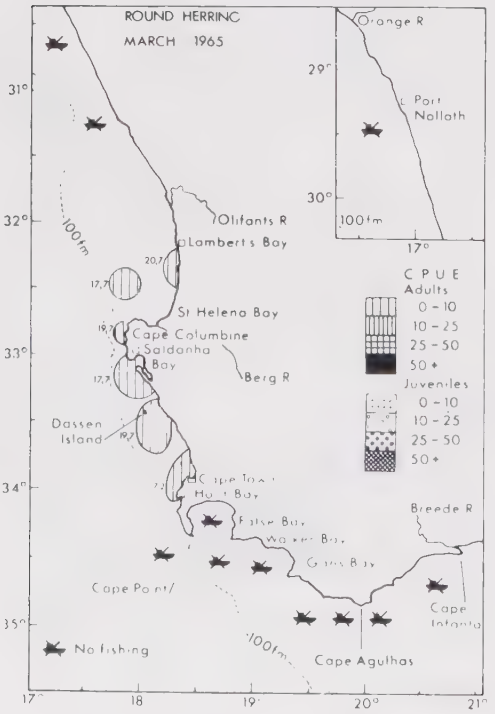
ROUND HERRING
MARCH 1965
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Juveniles
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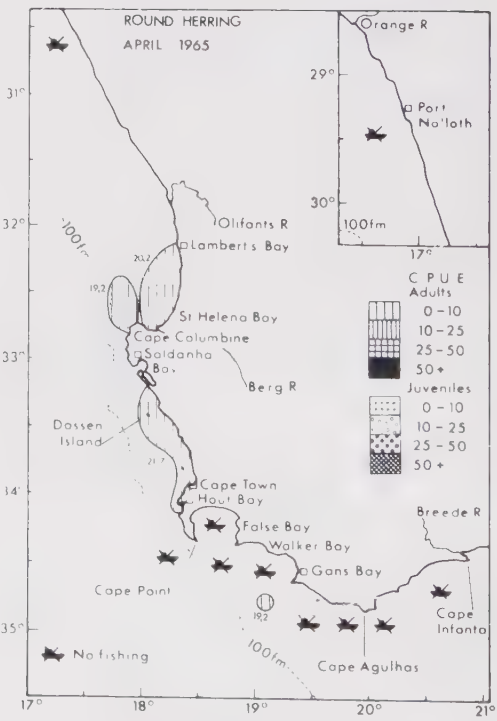
ROUND HERRING
APRIL 1965
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Port Nolloth
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
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Breede R
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Juveniles
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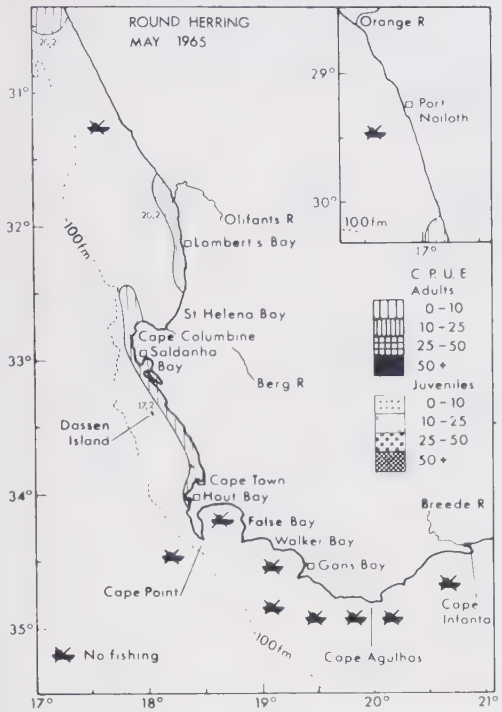
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MAY 1965
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
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Saldanha Bay
Berg R
Dassen Island
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100fm
No fishing
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Juveniles
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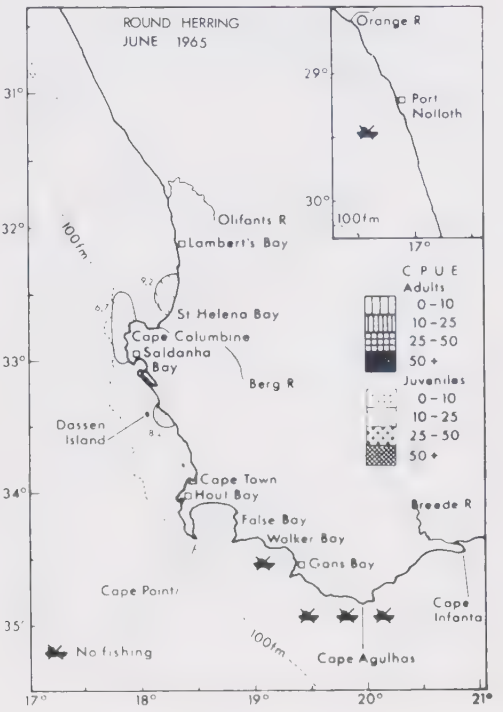
ROUND HERRING
JUNE 1965
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Port Nolloth
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
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Cape Point
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Cape Agulhas
100fm
No fishing
C P U E
Adults
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Juveniles
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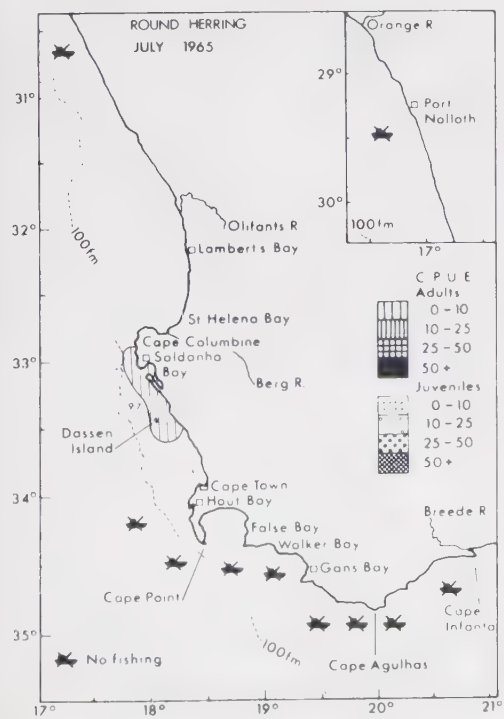
ROUND HERRING
JULY 1965
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Port Nolloth
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
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No fishing
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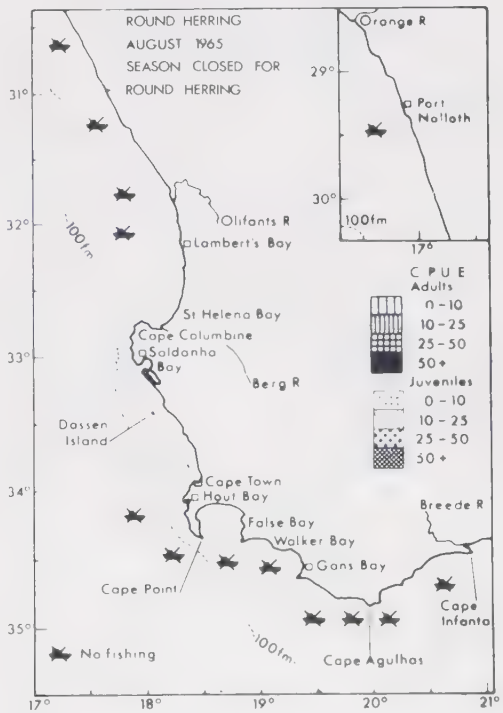
ROUND HERRING
AUGUST 1965
SEASON CLOSED FOR
ROUND HERRING
Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Juveniles
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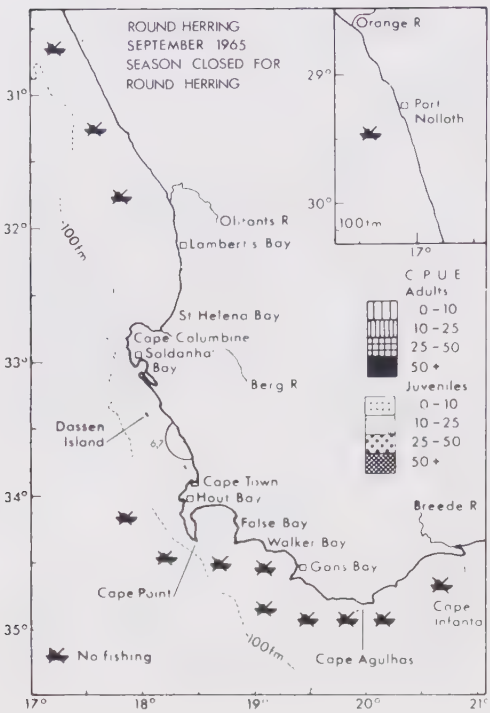
ROUND HERRING
SEPTEMBER 1965
SEASON CLOSED FOR
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
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Cape Town
Hout Bay
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Juveniles
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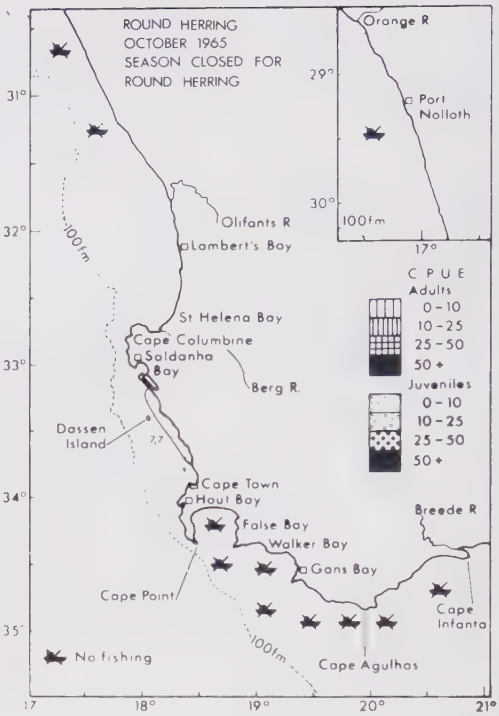
ROUND HERRING
OCTOBER 1965
SEASON CLOSED FOR
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Orange R
Port Nolloth
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
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Juveniles
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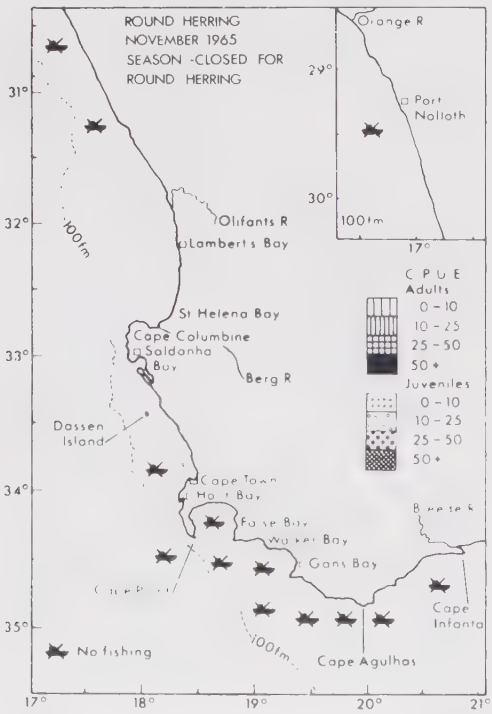
ROUND HERRING
NOVEMBER 1965
SEASON -CLOSED FOR
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
False Bay
Walker Bay
Gans Bay
Cape Infanta
Cape Agulhas
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Juveniles
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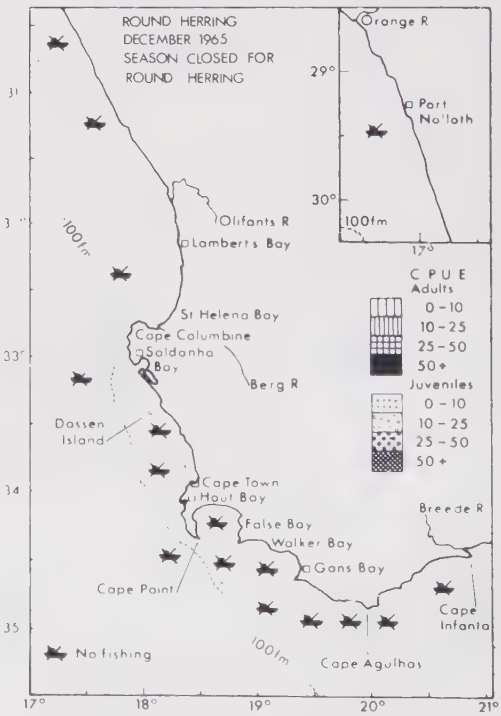
ROUND HERRING
DECEMBER 1965
SEASON CLOSED FOR
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Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Juveniles
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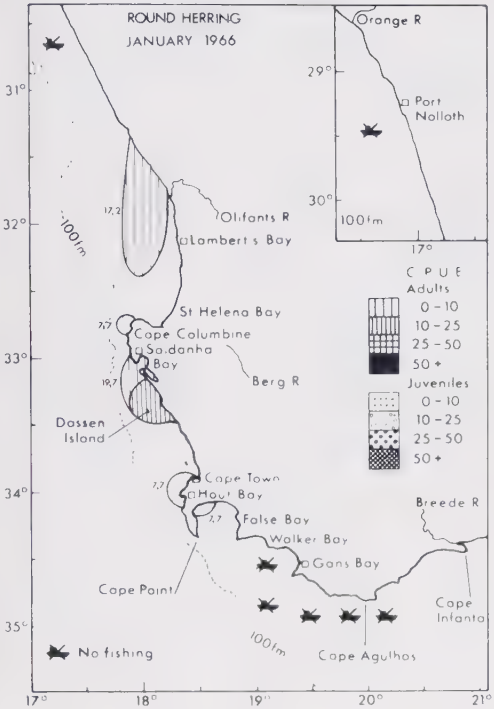
ROUND HERRING
JANUARY 1966
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Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
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Gans Bay
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Cape Infanta
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No fishing
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Juveniles
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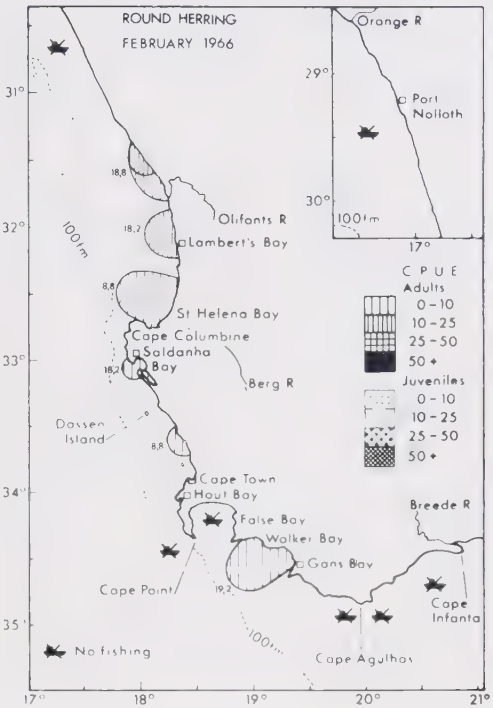
ROUND HERRING
FEBRUARY 1966
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
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Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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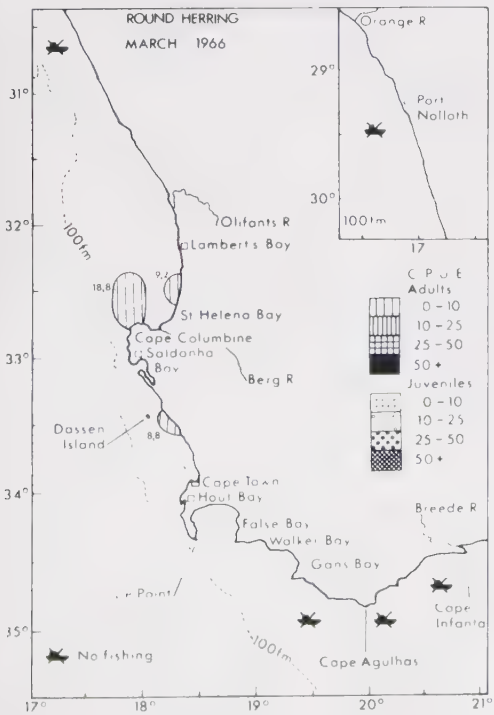
ROUND HERRING
MARCH 1966
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Lambert's Bay
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Cape Columbine
Saldanha Bay
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Dassen Island
Cape Town
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Cape Infanta
Cape Agulhas
No fishing
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Juveniles
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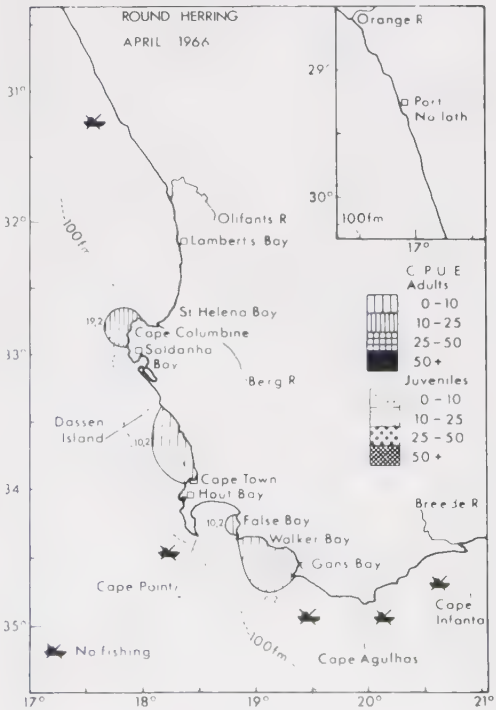
ROUND HERRING
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Juveniles
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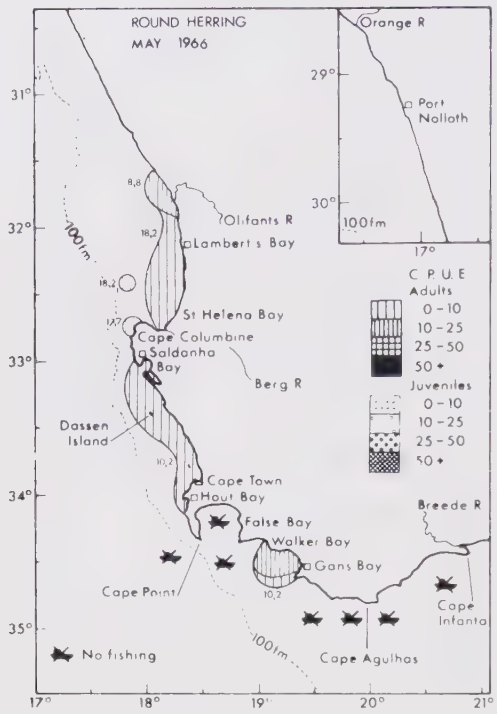
ROUND HERRING
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Cape Town
Hout Bay
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Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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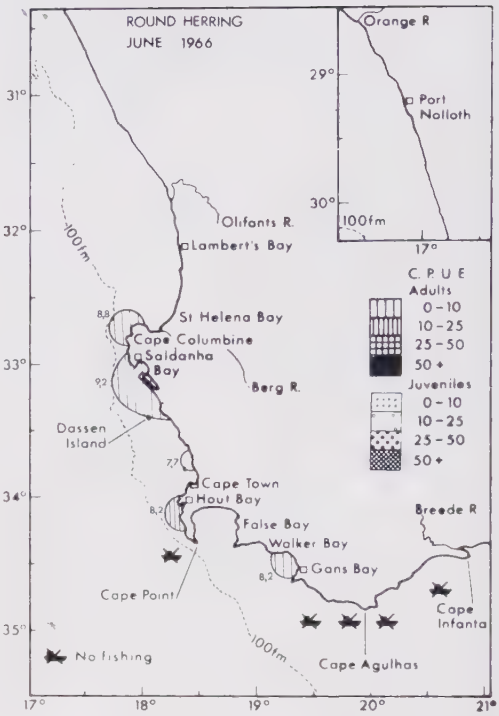
ROUND HERRING
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Lambert's Bay
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Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
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Walker Bay
Gans Bay
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Cape Point
Cape Infanta
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No fishing
C P U E
Adults
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Juveniles
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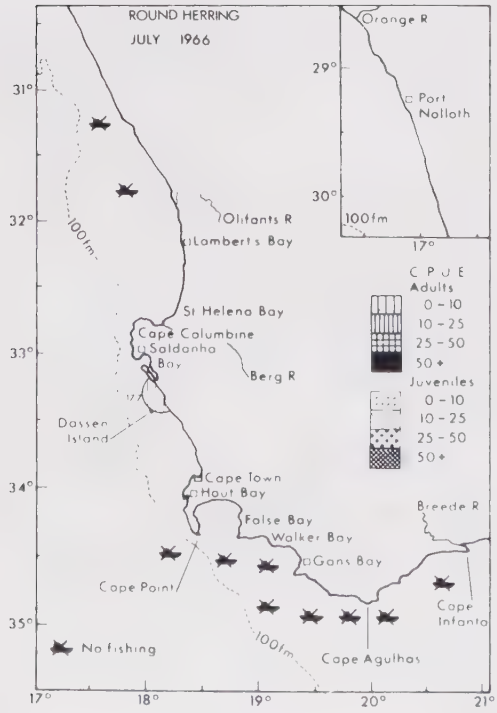
ROUND HERRING
JULY 1966
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Olifants R
Lambert's Bay
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Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
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Walker Bay
Gans Bay
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Cape Point
Cape Infanta
Cape Agulhas
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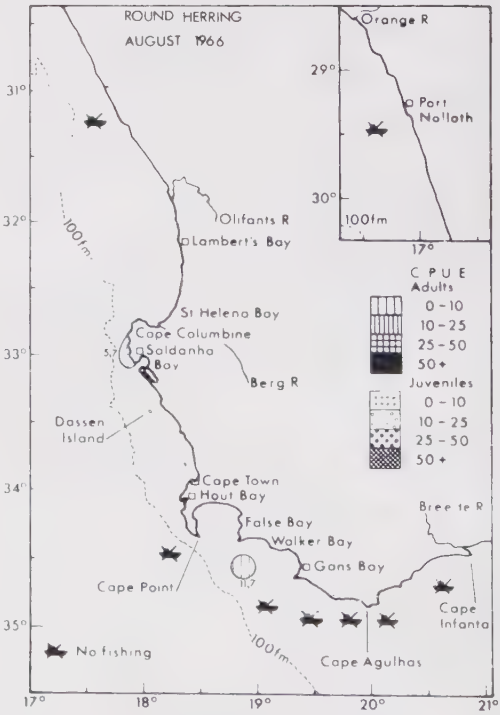
ROUND HERRING
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Lambert's Bay
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Cape Columbine
Saldanha Bay
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Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Juveniles
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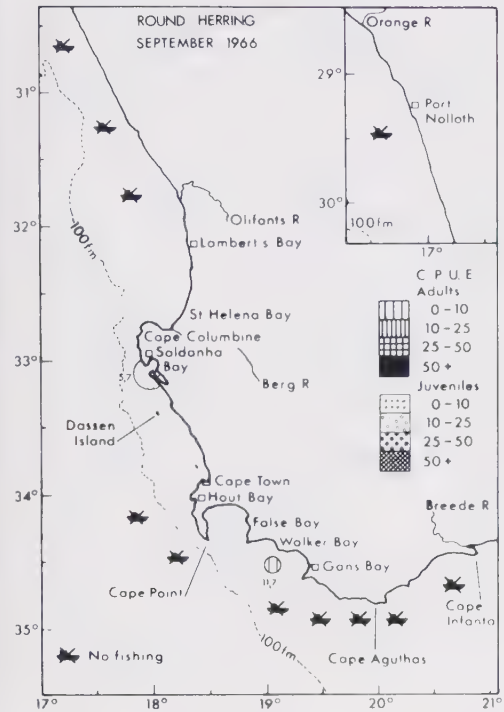
ROUND HERRING
SEPTEMBER 1966
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Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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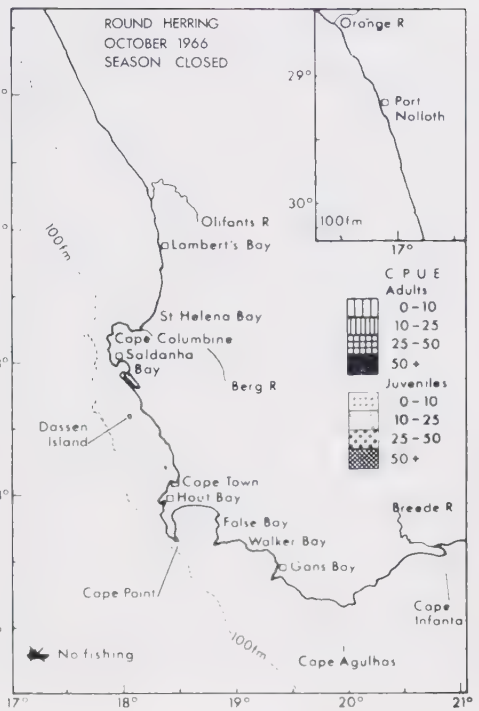
ROUND HERRING
OCTOBER 1966
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Orange R
Port Nolloth
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
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Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
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Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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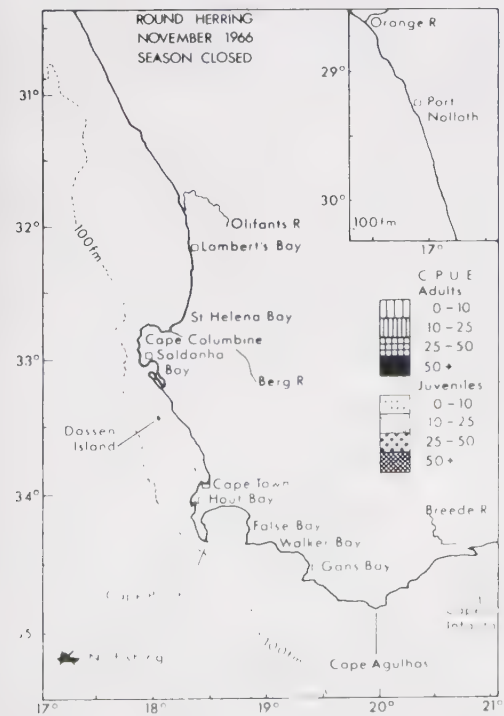
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St Helena Bay
Cape Columbine
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Berg R
Dassen Island
Cape Town
Hout Bay
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Juveniles
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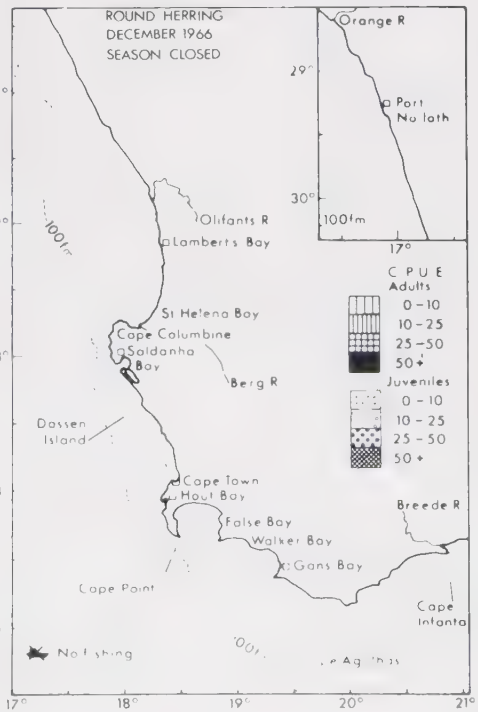
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Cape Columbine
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Berg R
Dassen Island
Cape Town
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False Bay
Walker Bay
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Juveniles
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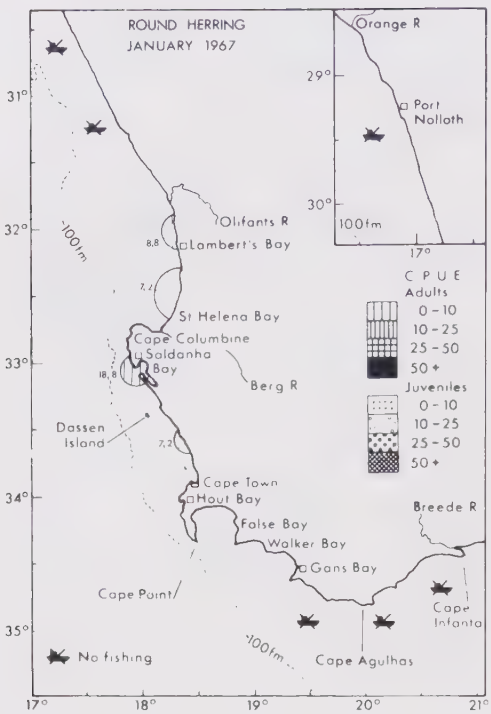
ROUND HERRING
JANUARY 1967
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Port Nolloth
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Lambert's Bay
St Helena Bay
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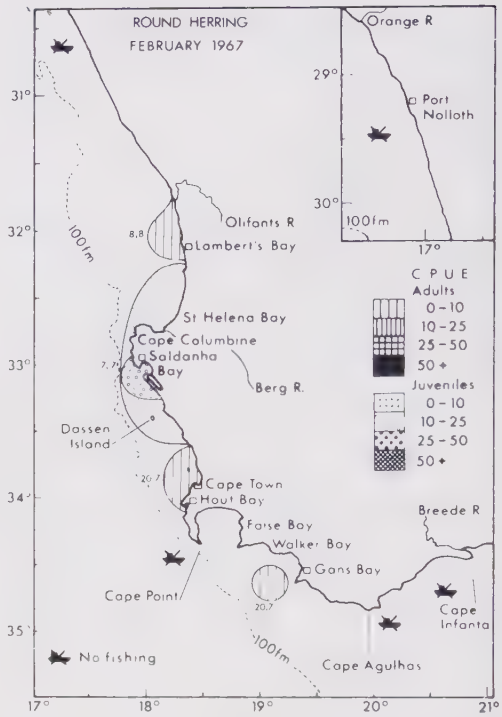
ROUND HERRING
FEBRUARY 1967
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Port Nolloth
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Lambert's Bay
St Helena Bay
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Berg R.
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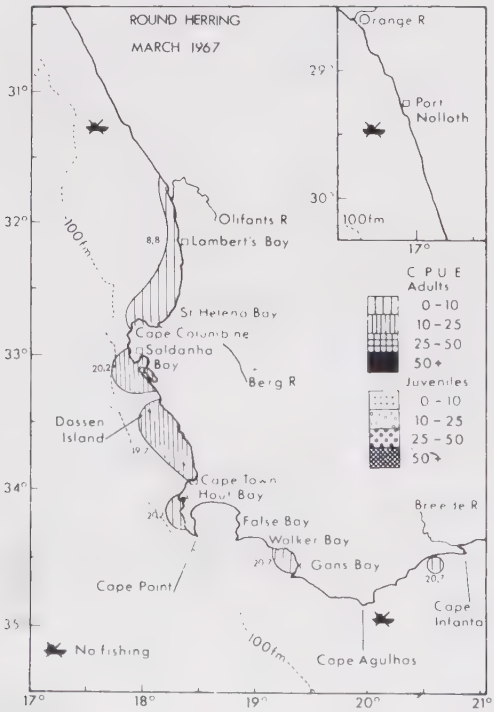
ROUND HERRING
MARCH 1967
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Lambert's Bay
St Helena Bay
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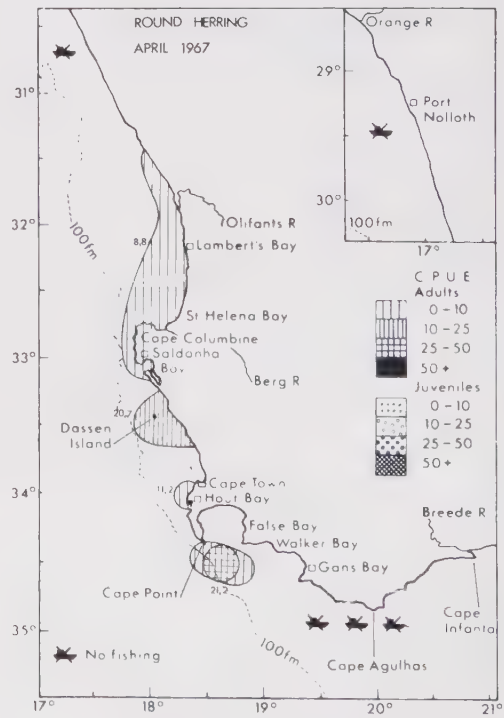
ROUND HERRING
APRIL 1967
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Lambert's Bay
St Helena Bay
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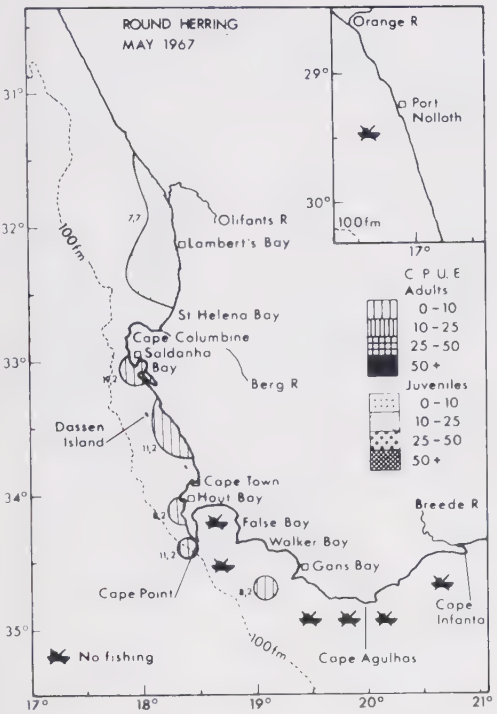
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MAY 1967
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Olifants R
Lambert's Bay
St Helena Bay
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Saldanha Bay
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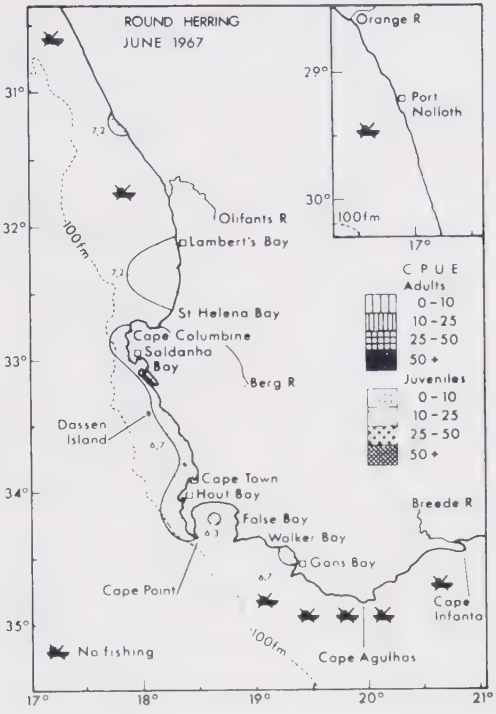
ROUND HERRING
JUNE 1967
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Olifants R
Lambert's Bay
St Helena Bay
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Saldanha Bay
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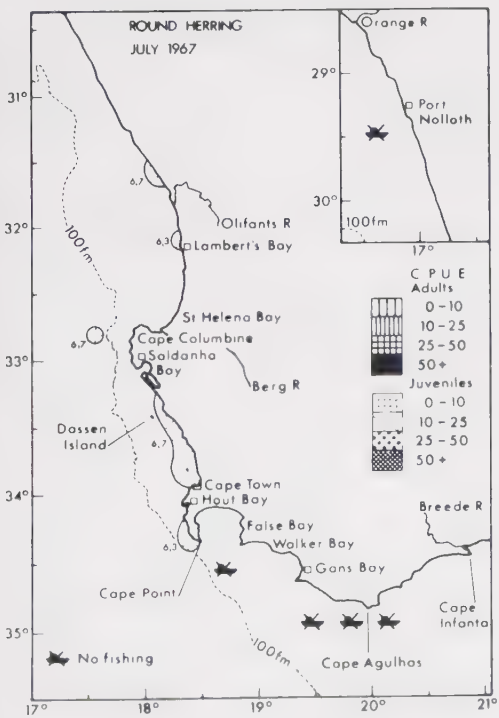
ROUND HERRING
JULY 1967
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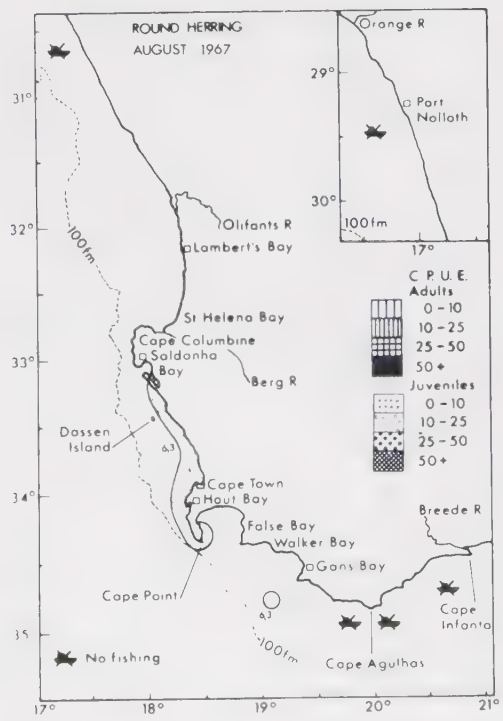
ROUND HERRING
AUGUST 1967
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Olifants R
Lambert's Bay
St Helena Bay
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Saldanha Bay
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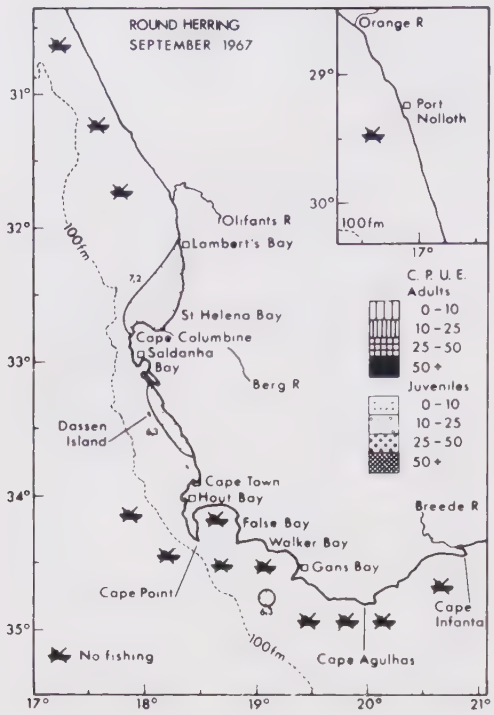
ROUND HERRING
SEPTEMBER 1967
Orange R
Port Nolloth
29°
30°
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17°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
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Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C. P. U. E.
Adults
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Juveniles
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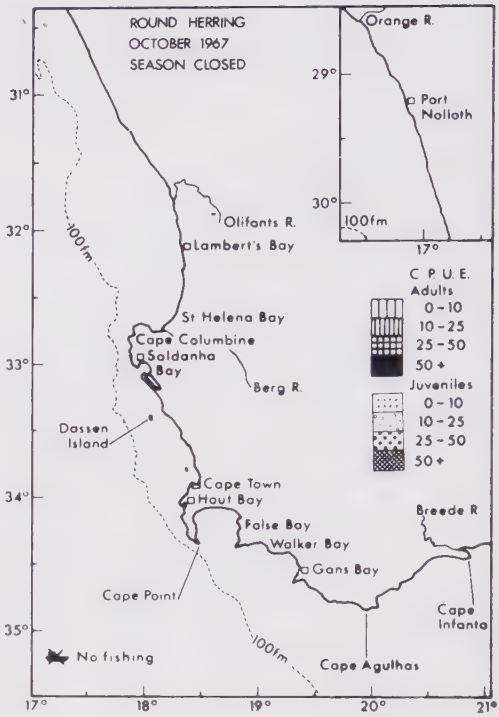
ROUND HERRING
OCTOBER 1967
SEASON CLOSED
Orange R.
Port Nolloth
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17°
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
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No fishing
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Adults
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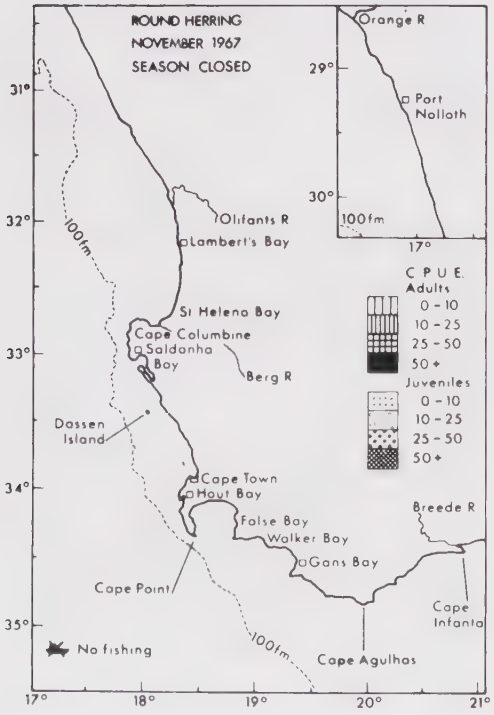
ROUND HERRING
NOVEMBER 1967
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St Helena Bay
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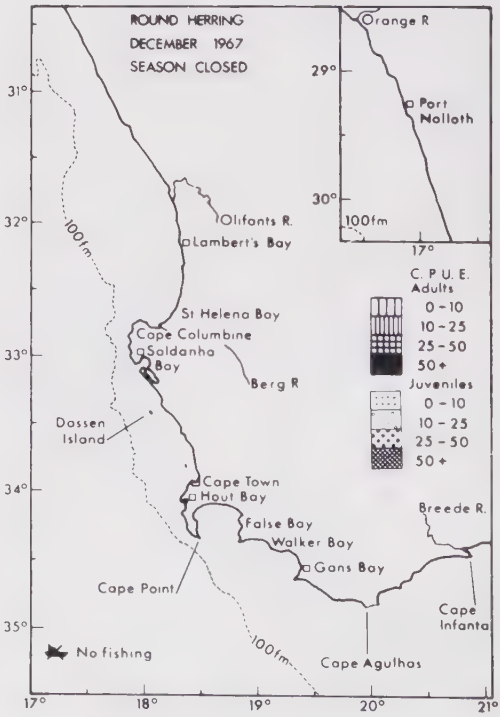
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DECEMBER 1967
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St Helena Bay
Cape Columbine
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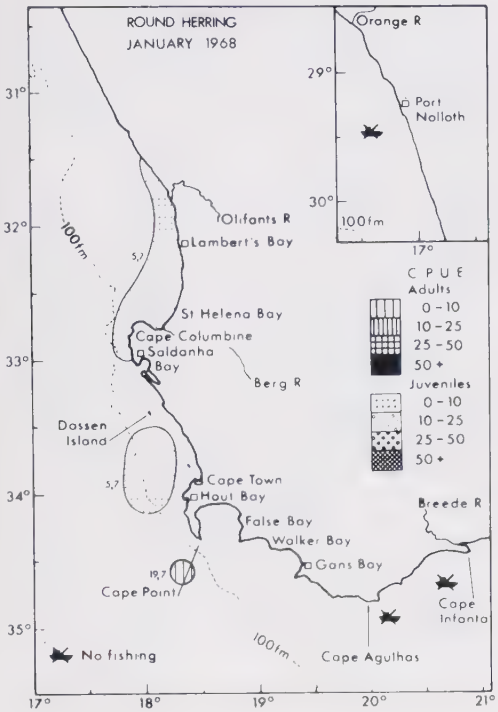
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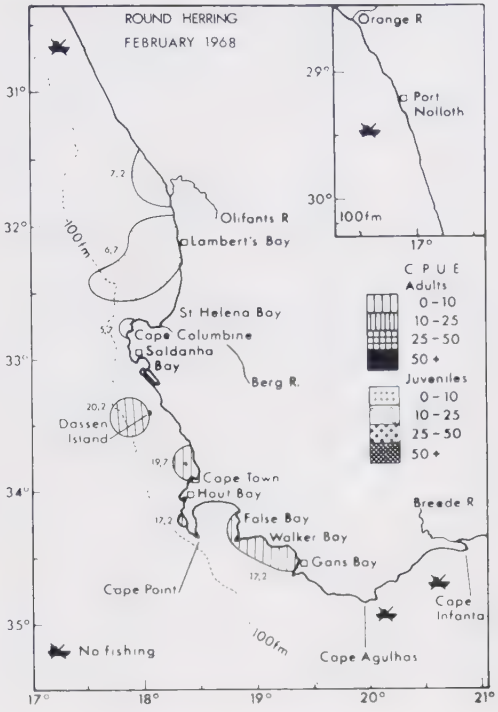
ROUND HERRING
FEBRUARY 1968
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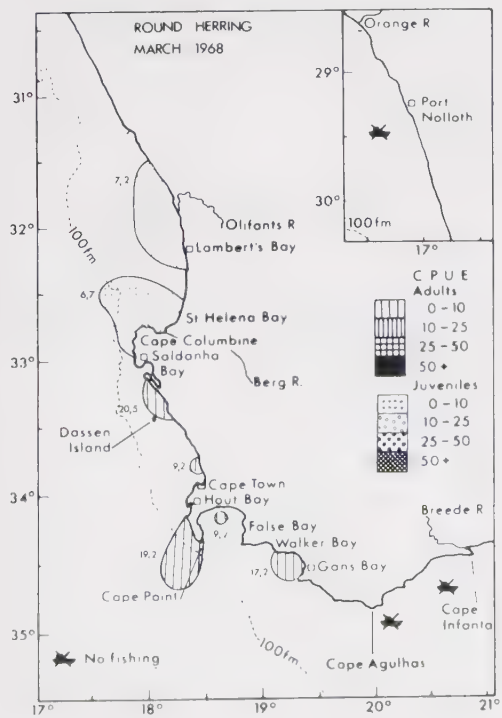
ROUND HERRING
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Dassen Island
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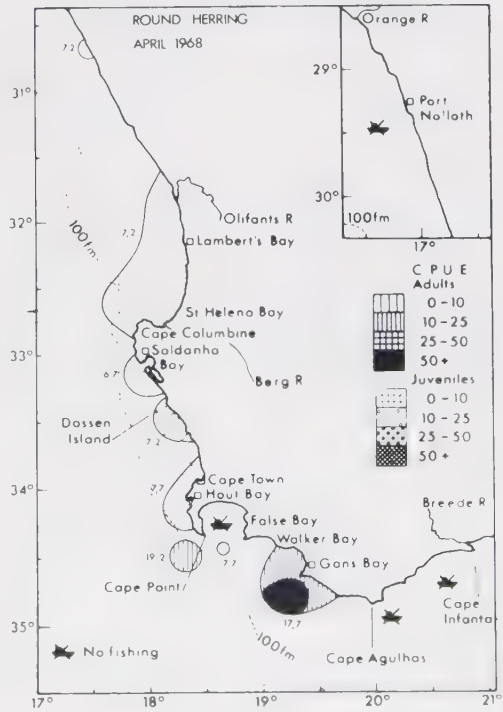
ROUND HERRING
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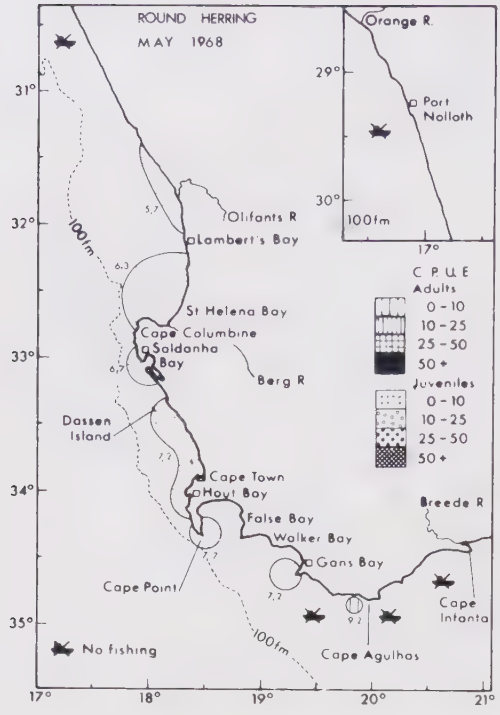
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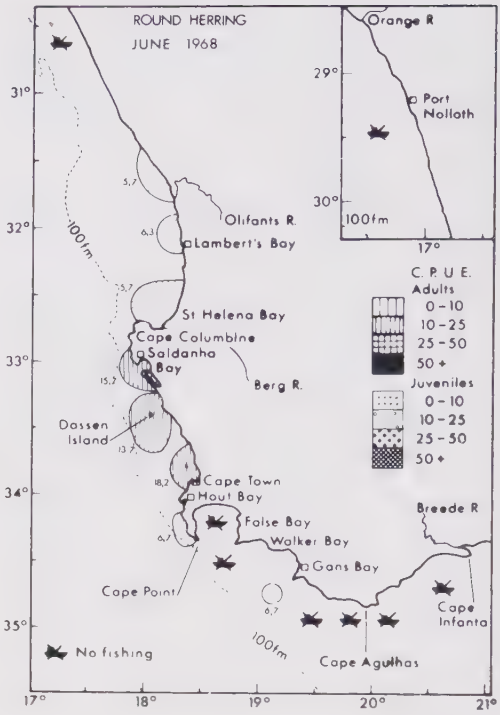
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Lambert's Bay
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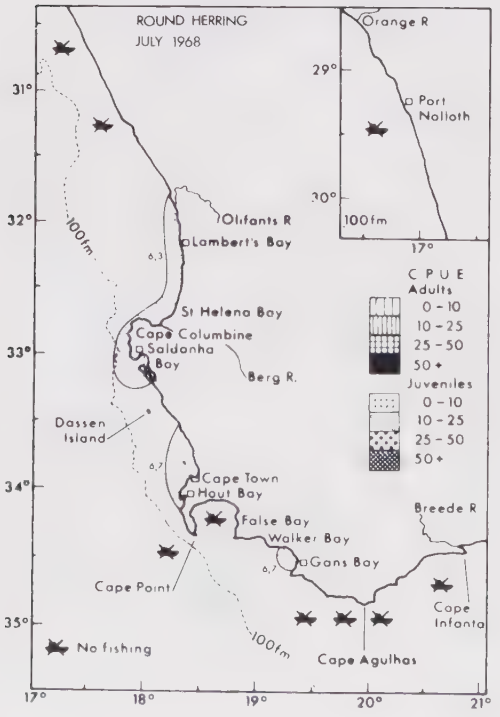
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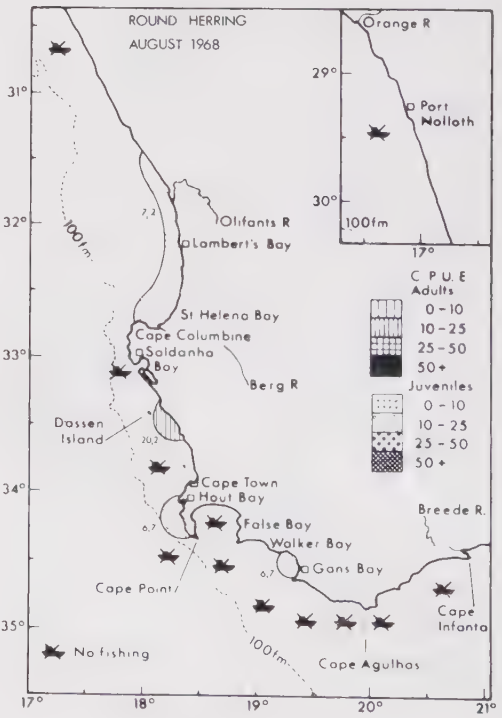
ROUND HERRING
AUGUST 1968
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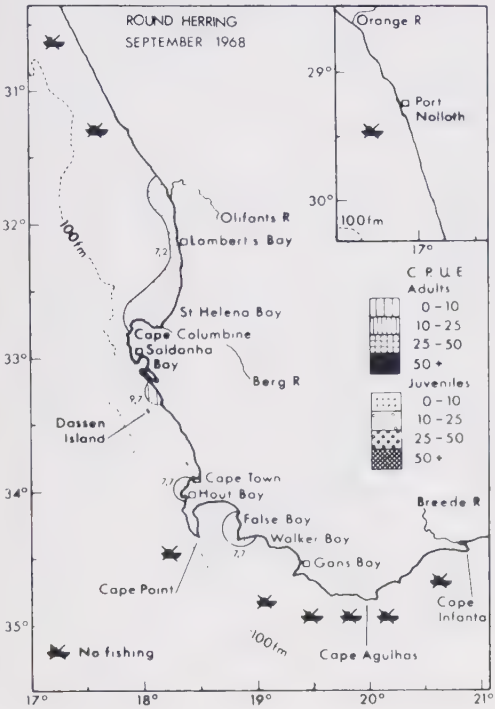
ROUND HERRING
SEPTEMBER 1968
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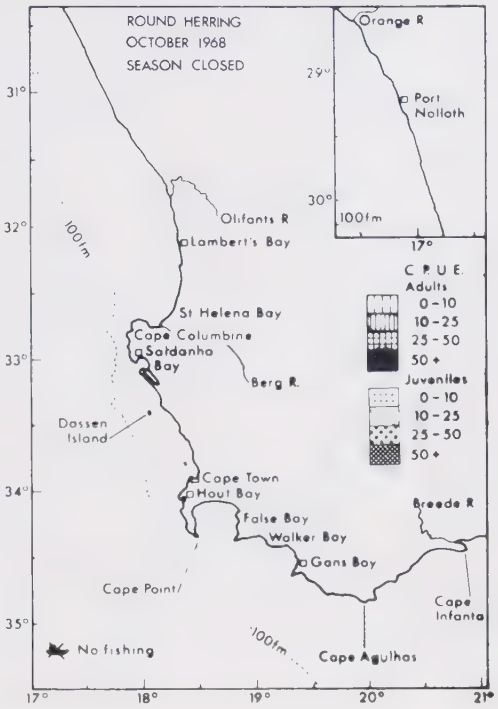
ROUND HERRING
OCTOBER 1968
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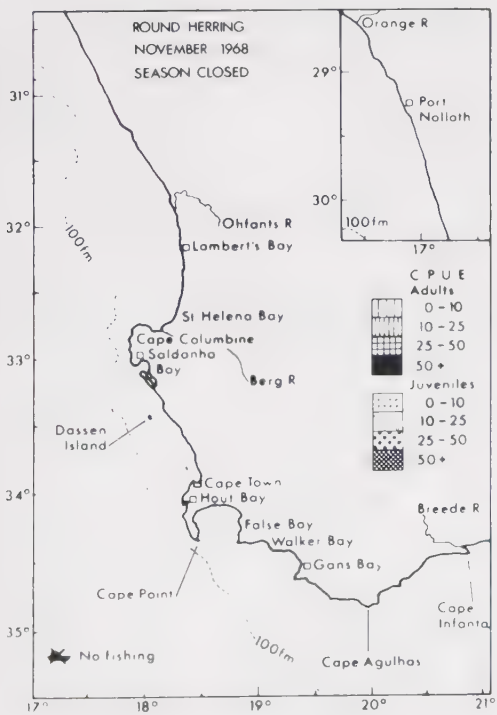
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NOVEMBER 1968
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Port Nolloth
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Adults
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Juveniles
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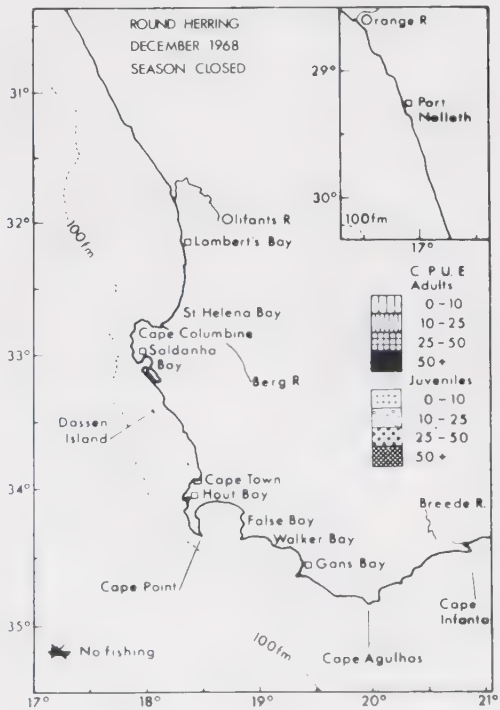
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Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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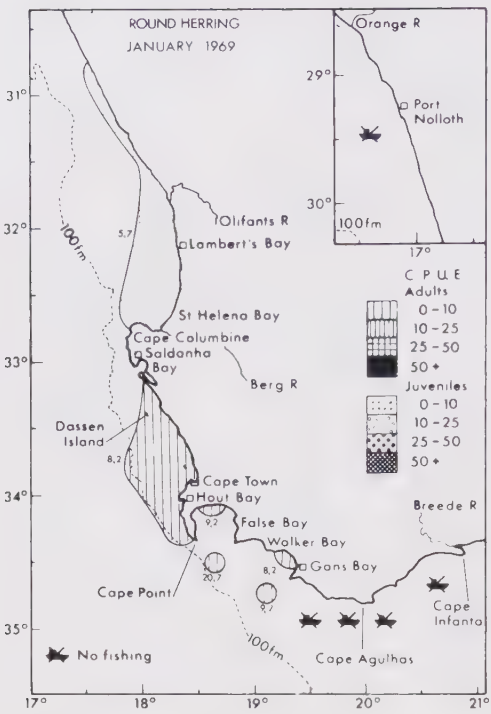
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Dassen Island
Cape Town
Hout Bay
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Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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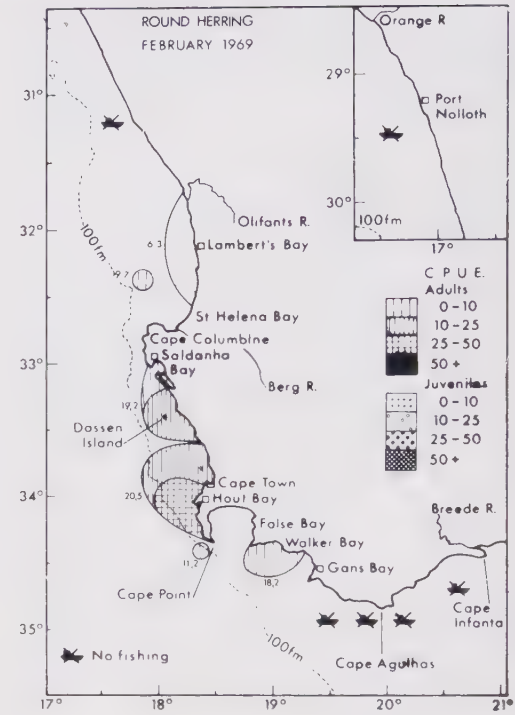
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Berg R.
Dassen Island
Cape Town
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False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
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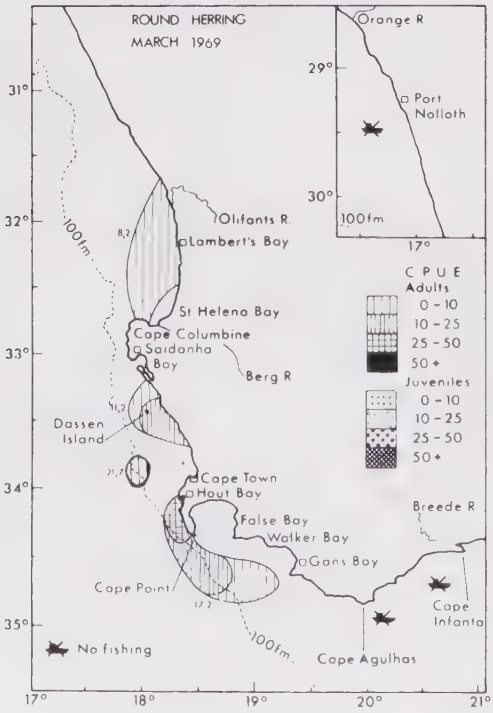
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Dassen Island
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Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
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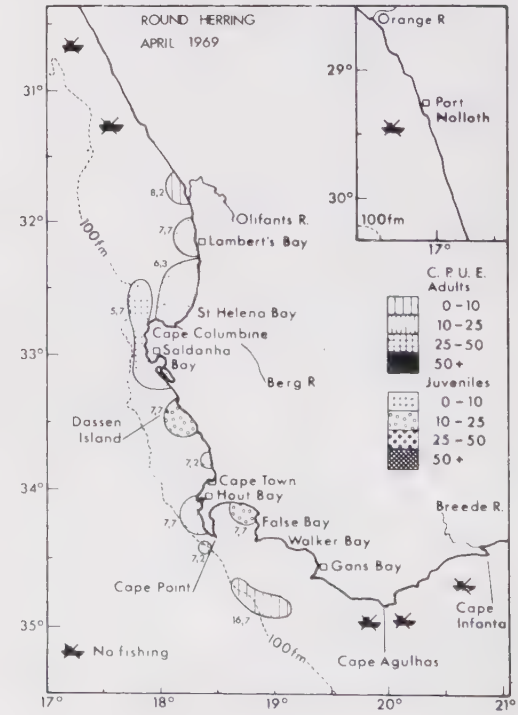
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Dassen Island
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False Bay
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Breede R.
Cape Point
Cape Infanta
Cape Agulhas
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Juveniles
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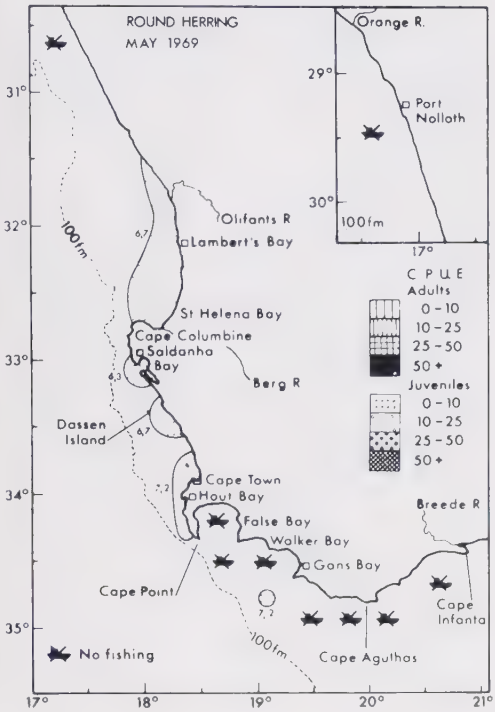
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Berg R
Dassen Island
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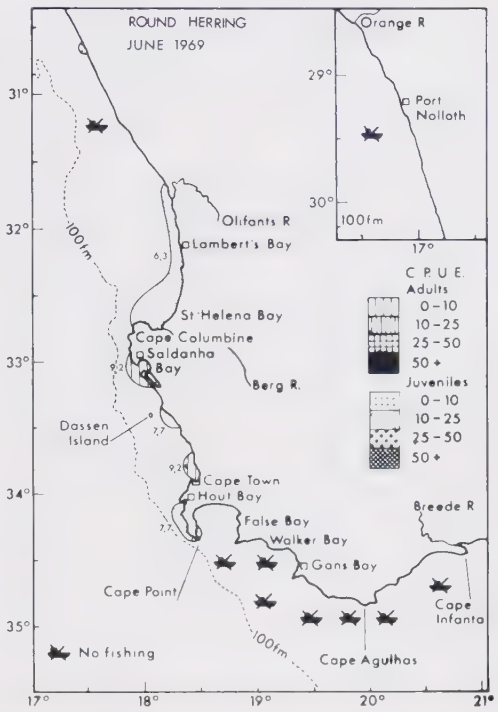
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Dassen Island
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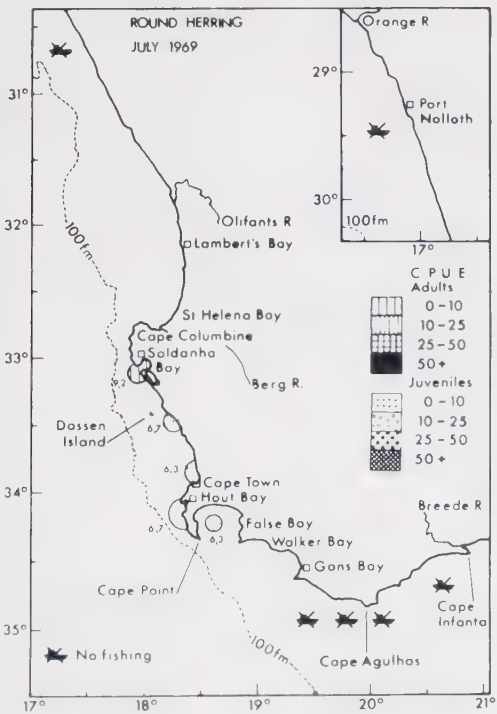
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Juveniles
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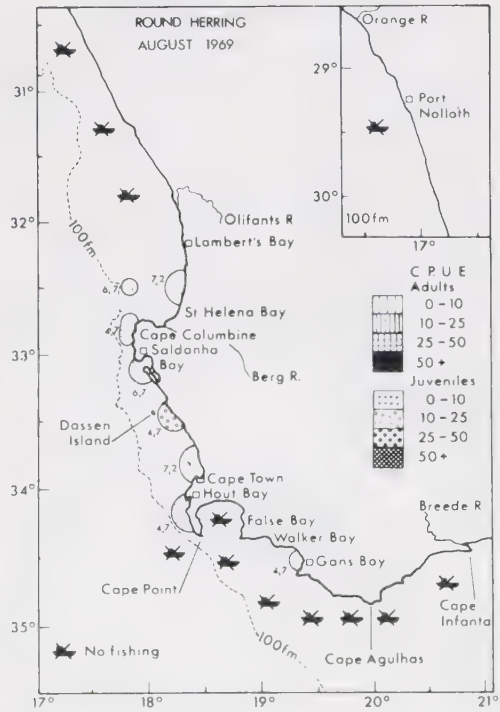
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AUGUST 1969
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Port Nolloth
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Lambert's Bay
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Berg R.
Dassen Island
Cape Town
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Juveniles
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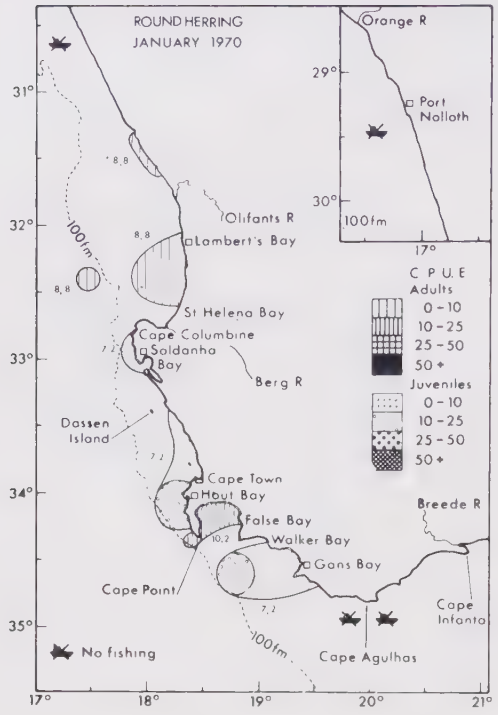
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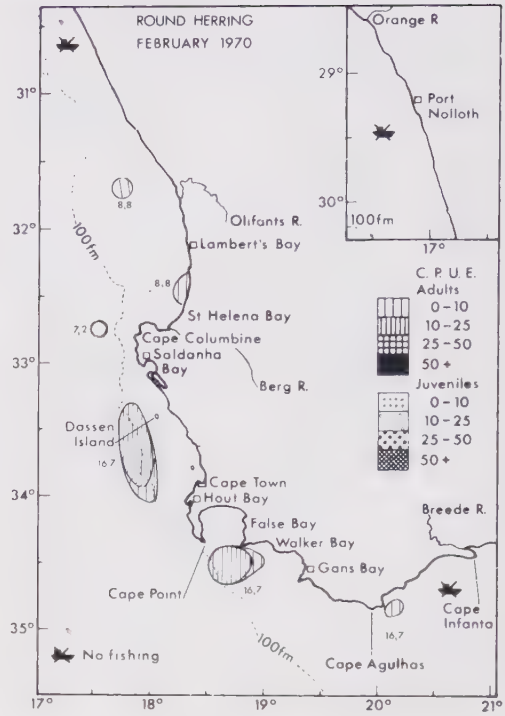
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Berg R.
Dassen Island
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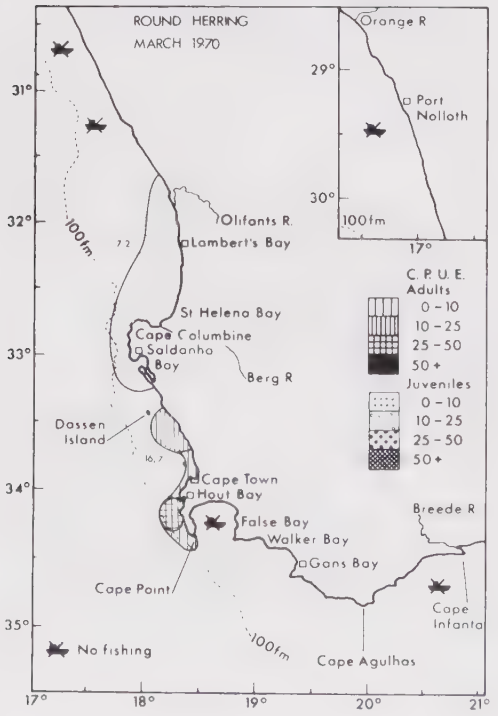
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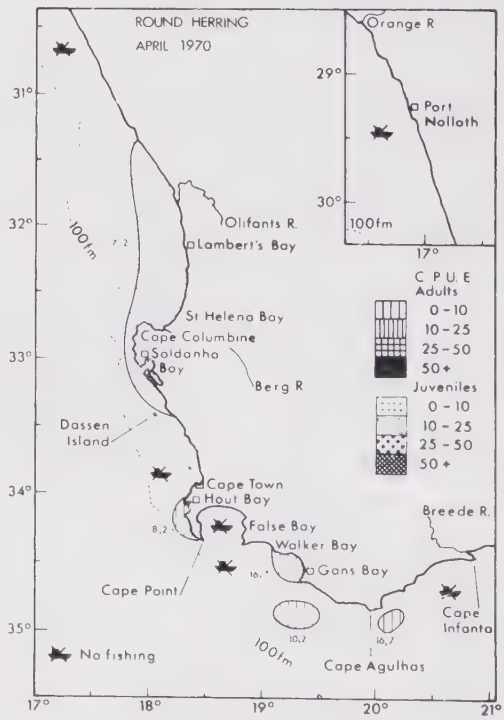
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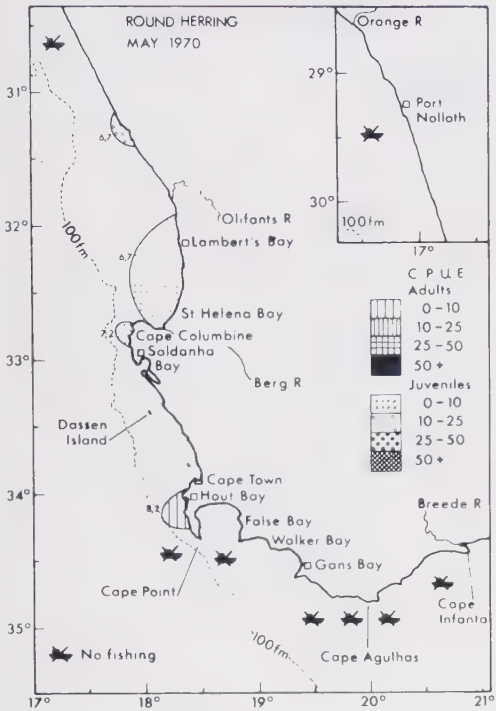
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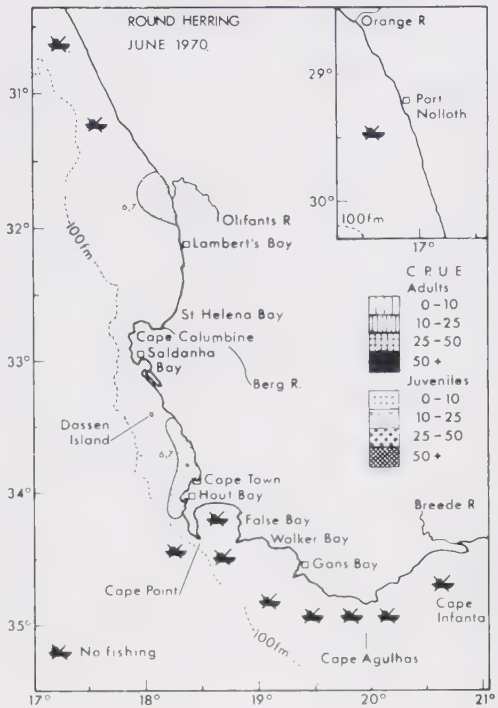
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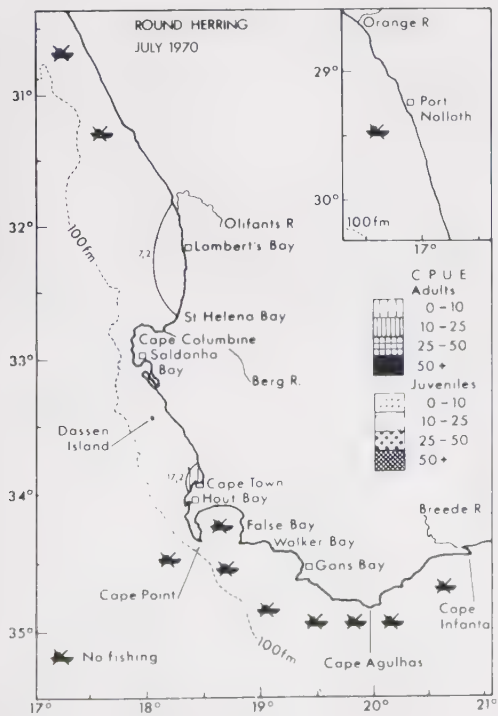
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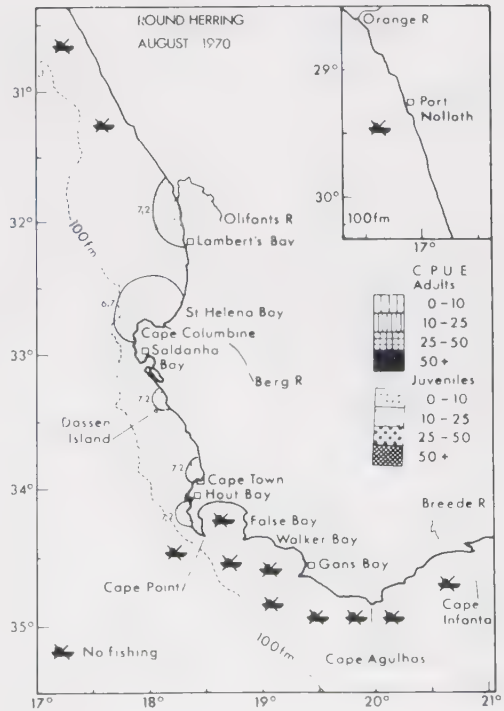
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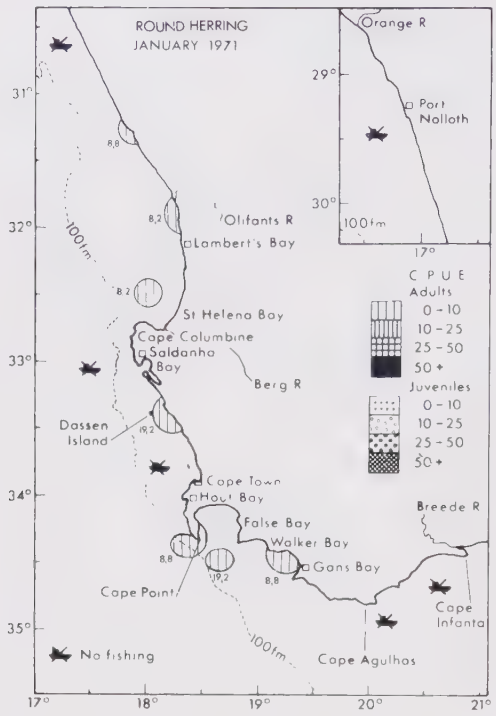
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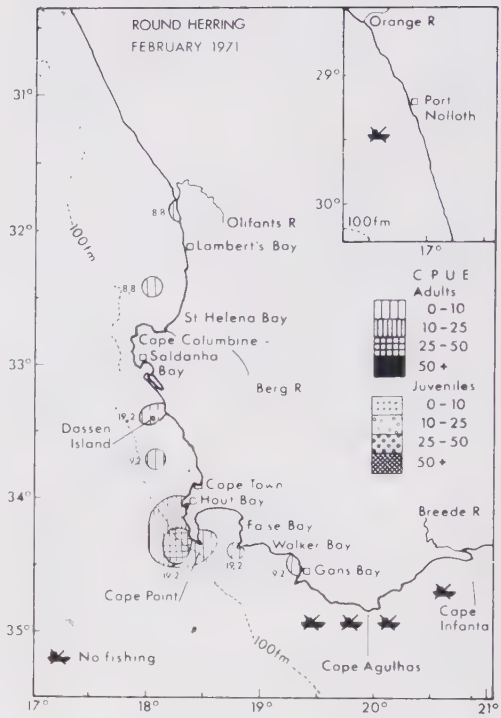
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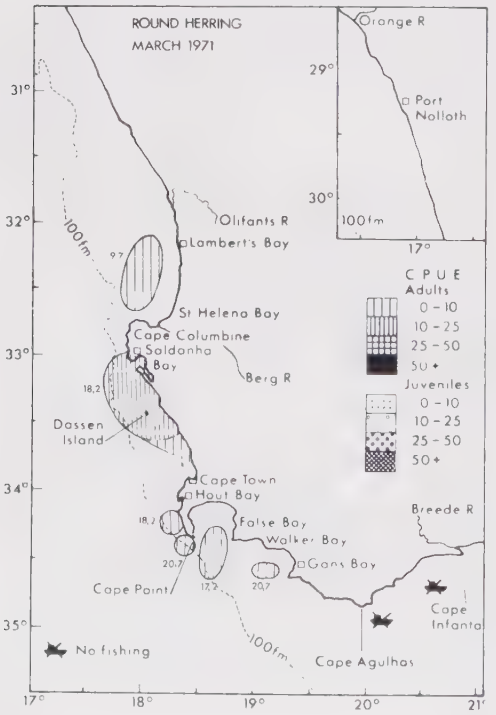
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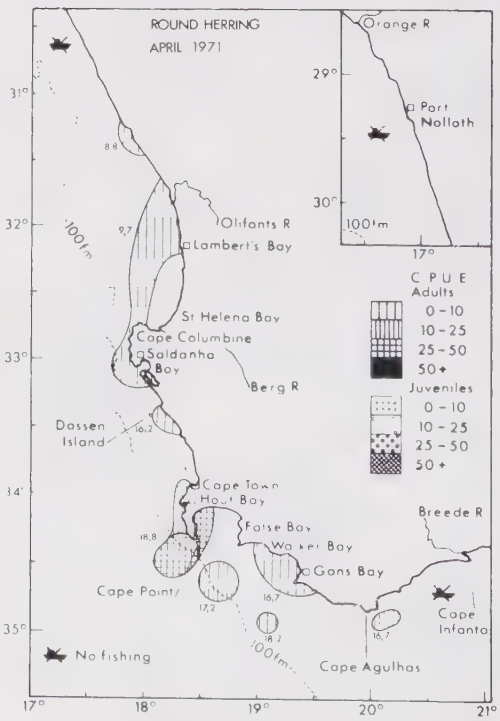
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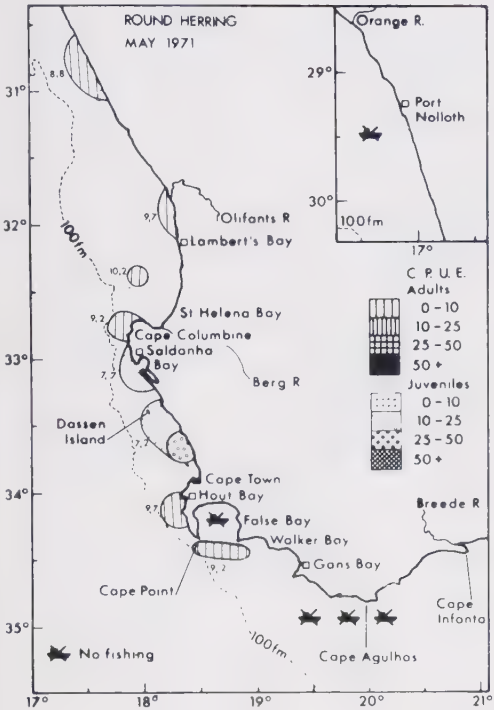
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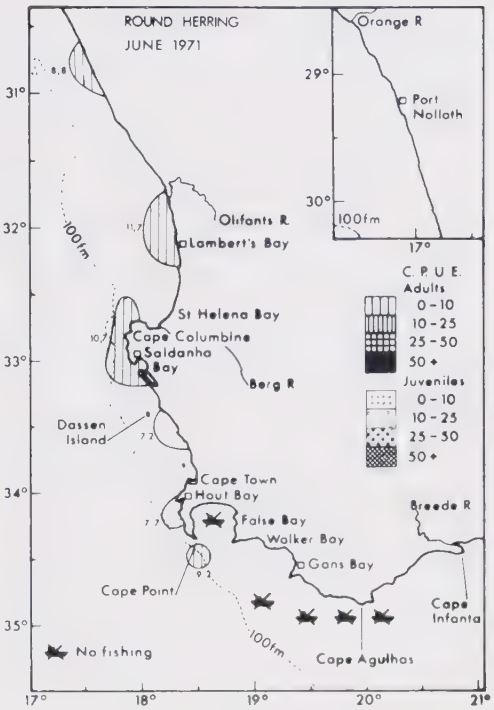
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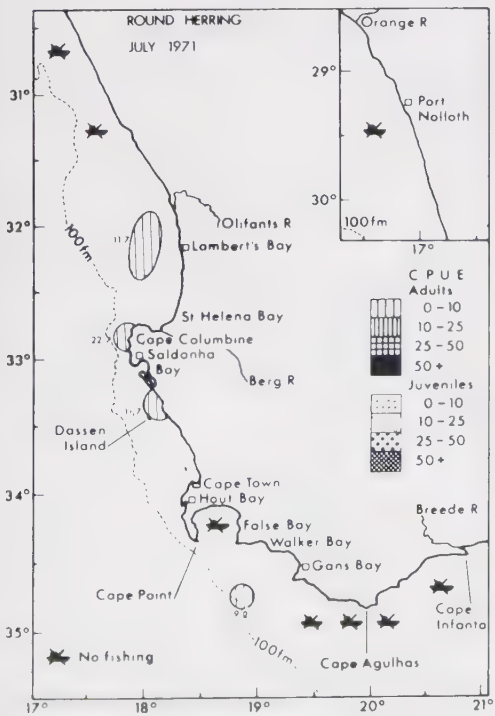
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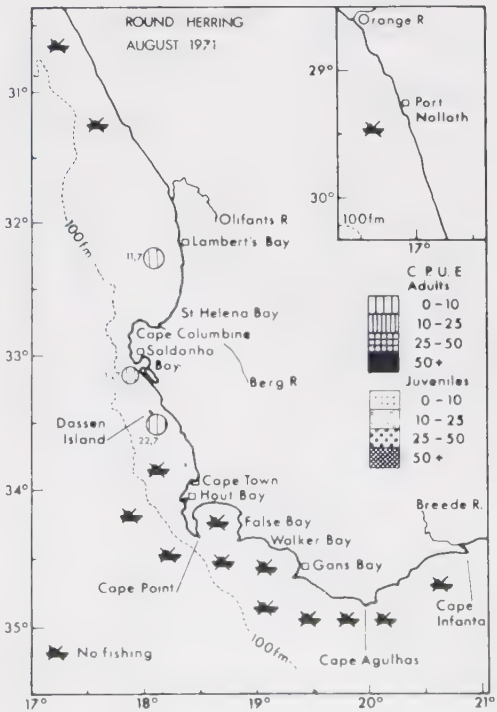
ROUND HERRING
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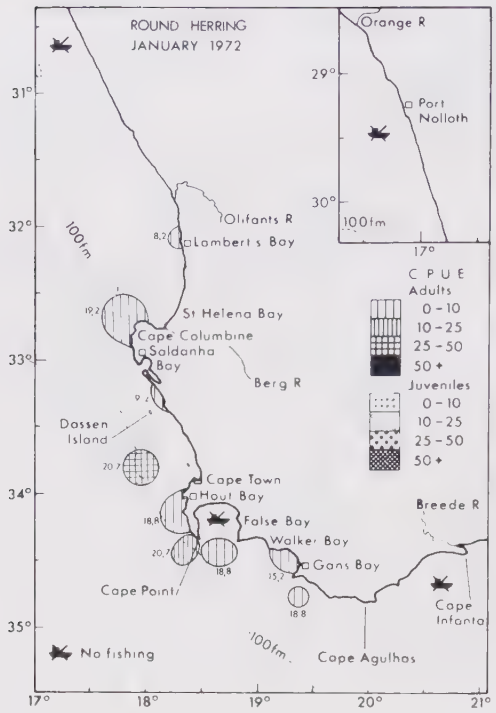
ROUND HERRING
JANUARY 1972
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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25 - 50
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Juveniles
0 - 10
10 - 25
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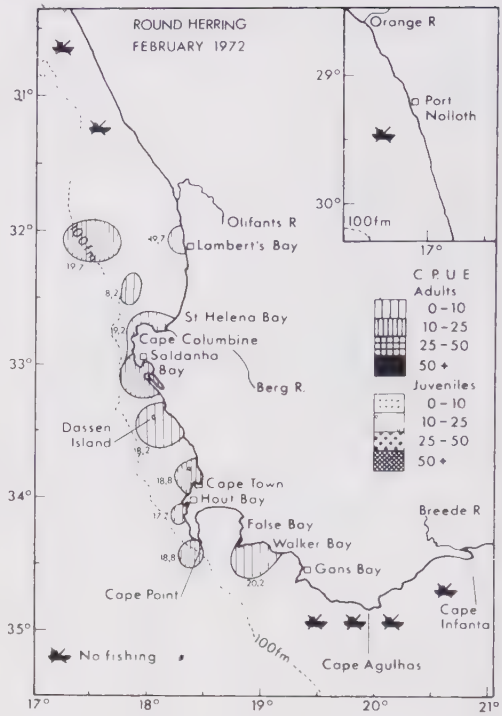
ROUND HERRING
FEBRUARY 1972
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Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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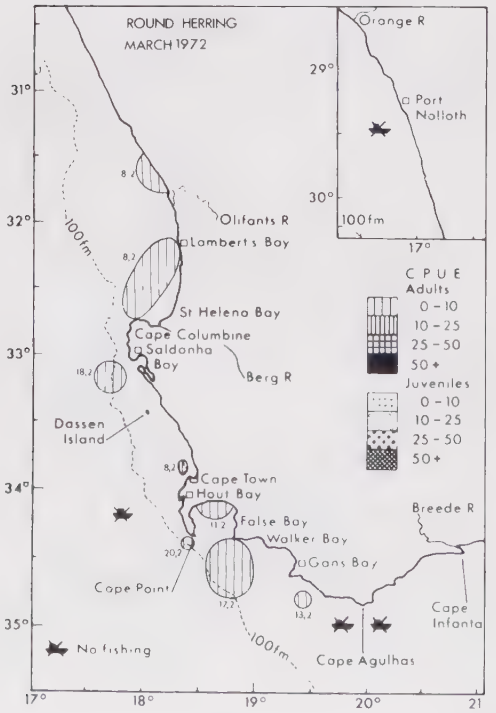
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MARCH 1972
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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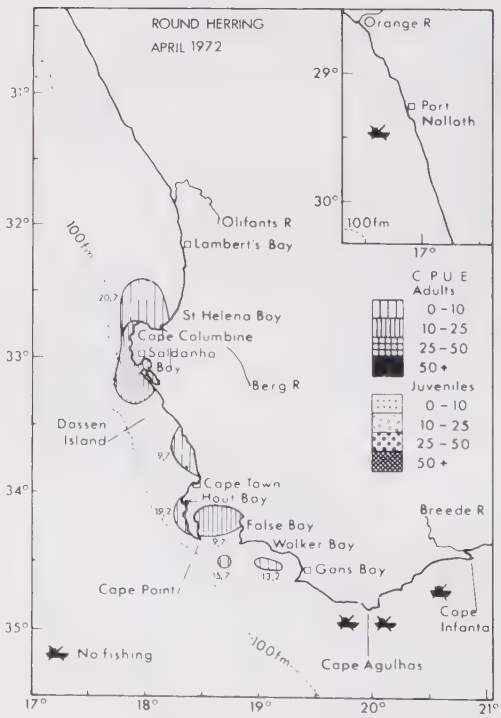
ROUND HERRING
APRIL 1972
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Port Nolloth
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Olifants R
Lambert's Bay
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Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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Juveniles
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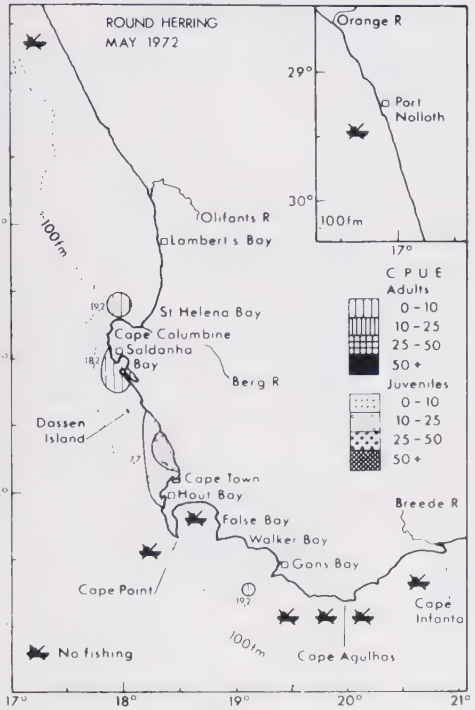
ROUND HERRING
MAY 1972
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Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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Adults
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Juveniles
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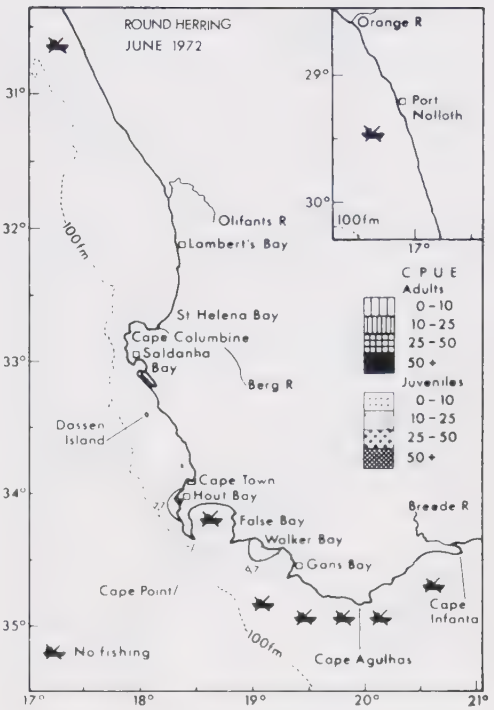
50 +


ROUND HERRING
JUNE 1972
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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Juveniles
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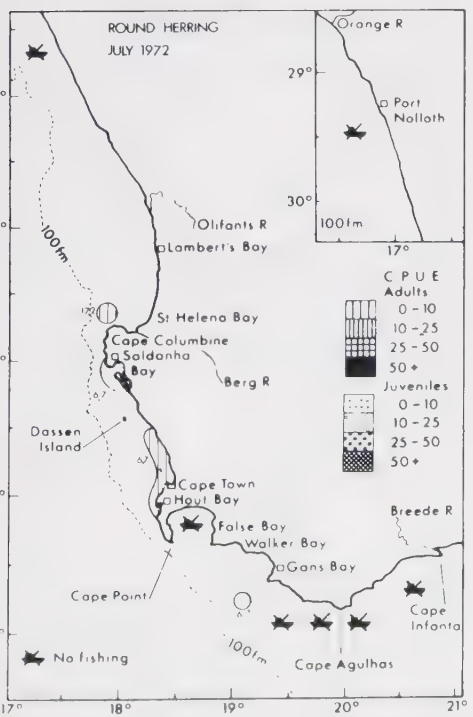
ROUND HERRING
JULY 1972
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Port Nolloth
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Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
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Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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10 - 25
25 - 50
50 +
Juveniles
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10 - 25
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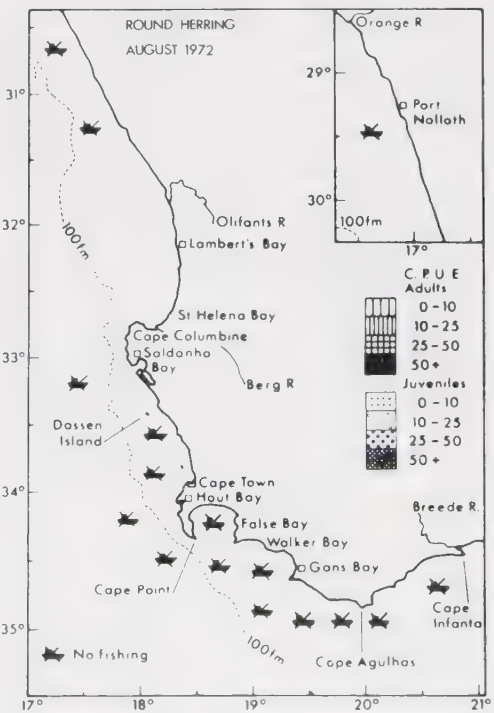
50 +


ROUND HERRING
AUGUST 1972
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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25 - 50
50 +
Juveniles
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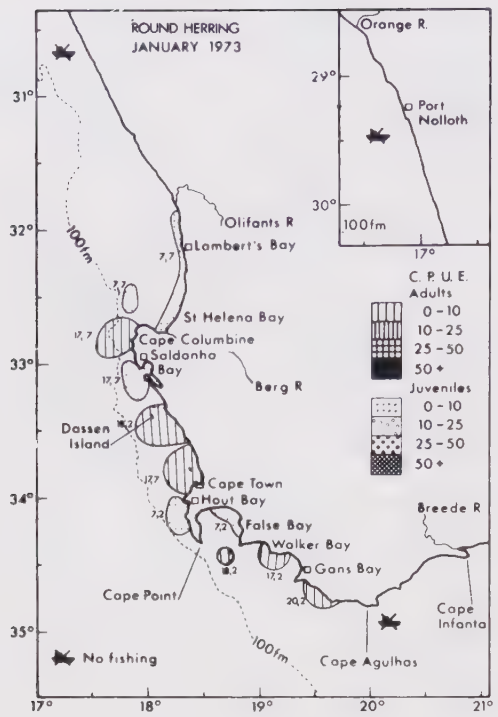
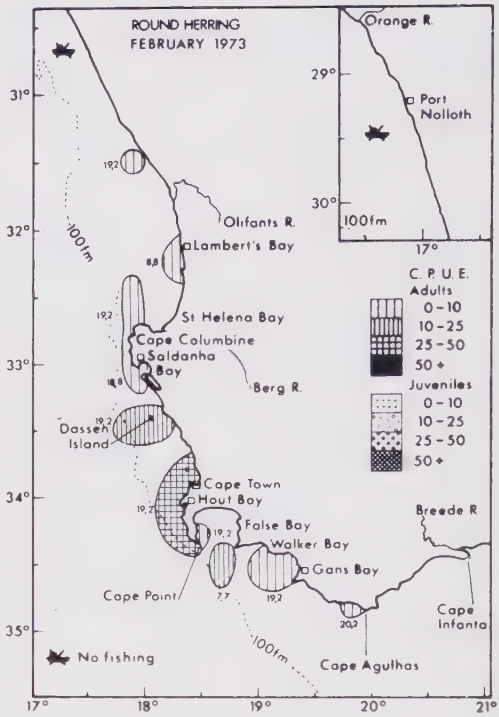
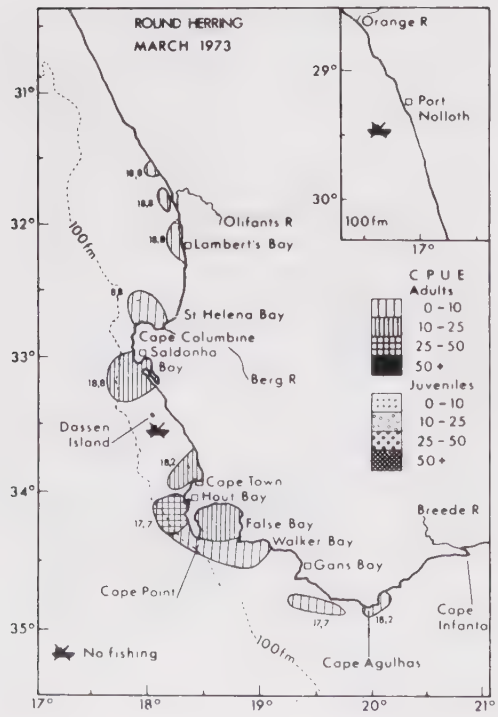
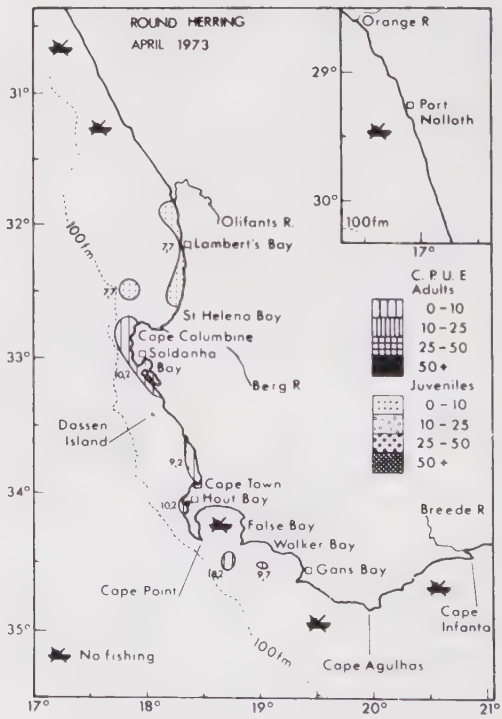
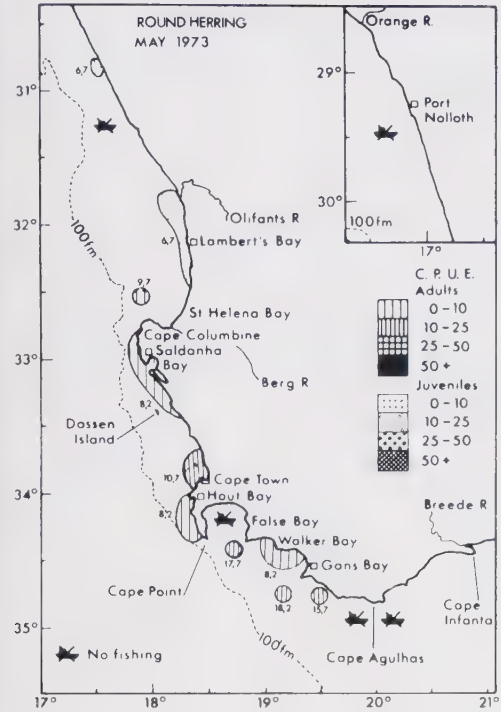
50 +

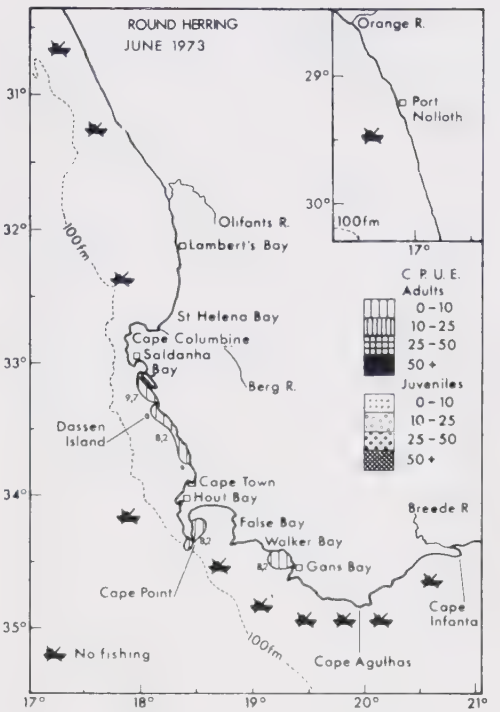

ROUND HERRING
JANUARY 1973
Orange R.
Port Nolloth
100fm
C. P. U. E.
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm

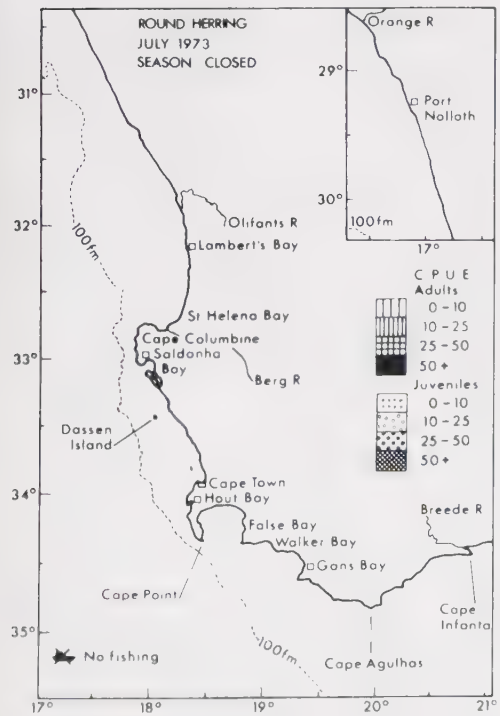

ROUND HERRING
FEBRUARY 1973
Orange R.
Port Nolloth
100fm
C. P. U. E.
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm

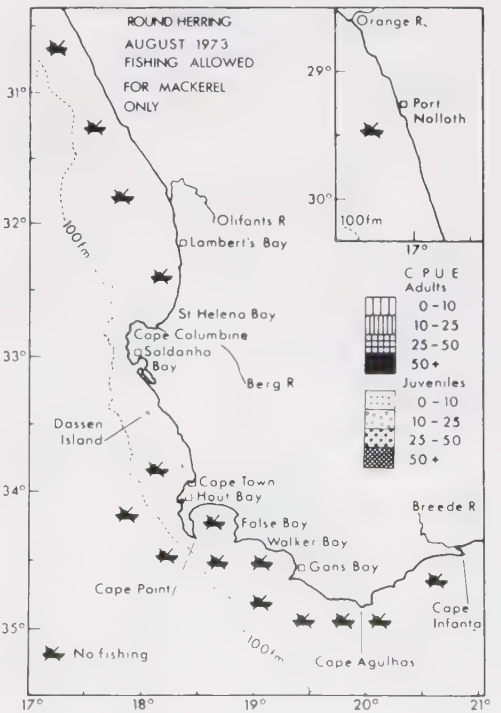

ROUND HERRING
MARCH 1973
Orange R
Port Nolloth
100fm
C P U E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm


ROUND HERRING
APRIL 1973
Orange R
Port Nolloth
100fm
C. P. U. E
Adults
0 – 10
10 – 25
25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
100fm


ROUND HERRING
MAY 1973
Orange R.
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C. P. U. E.
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


ROUND HERRING
JUNE 1973
Orange R.
Port Nolloth
100fm
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


ROUND HERRING
JULY 1973
SEASON CLOSED
Orange R
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +


ROUND HERRING
AUGUST 1973
FISHING ALLOWED
FOR MACKEREL
ONLY
Orange R.
Port Nolloth
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
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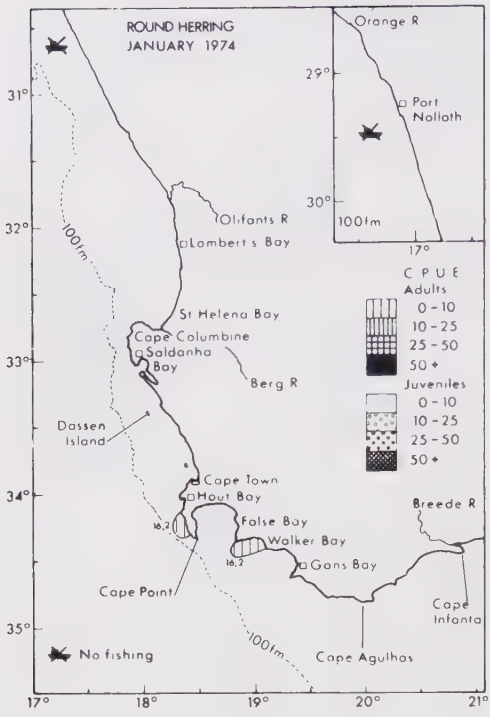
ROUND HERRING
JANUARY 1974
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
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Juveniles
0 - 10
10 - 25
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50 +
16,2
16,2
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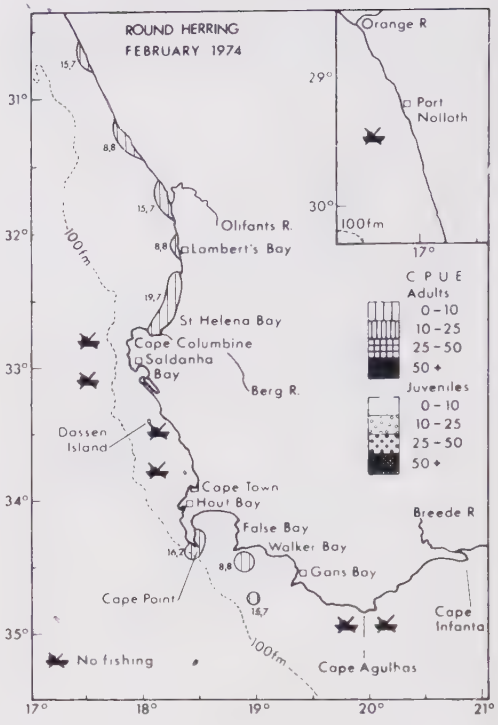
ROUND HERRING
FEBRUARY 1974
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
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33°
34°
35°
100fm
15,7
8,8
15,7
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19,7
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
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10 - 25
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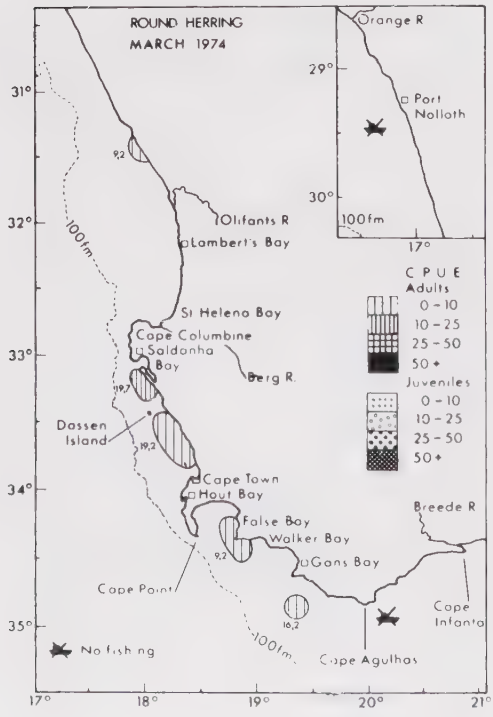
ROUND HERRING
MARCH 1974
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Port Nolloth
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100fm
9,2
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
19,7
Dassen Island
19,2
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
9,2
Cape Point
16,2
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
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25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
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18°
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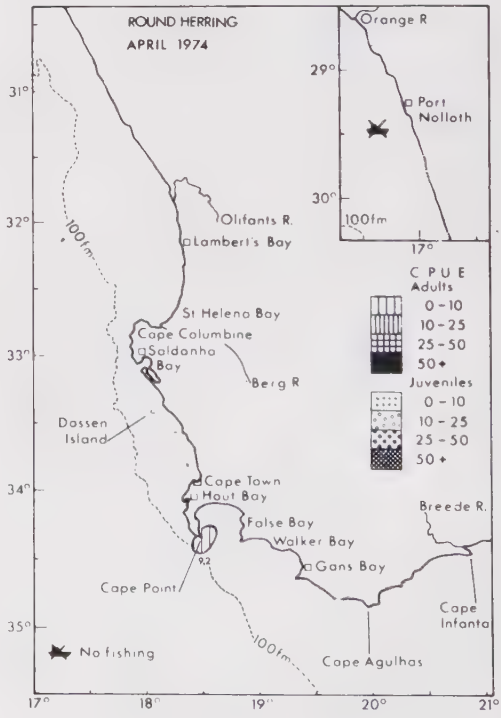
ROUND HERRING
APRIL 1974
Orange R
Port Nolloth
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100fm
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
9,2
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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50 +
Juveniles
0 - 10
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25 - 50
50 +
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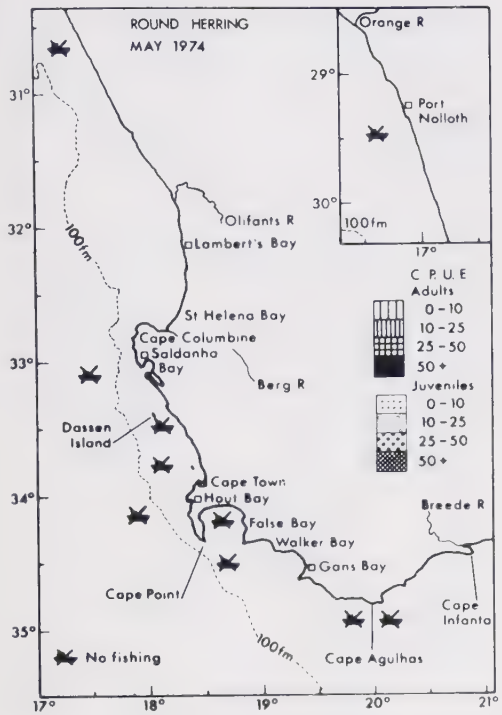
ROUND HERRING
MAY 1974
Orange R
Port Nolloth
29°
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100fm
17°
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Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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25 - 50
50 +
Juveniles
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50 +
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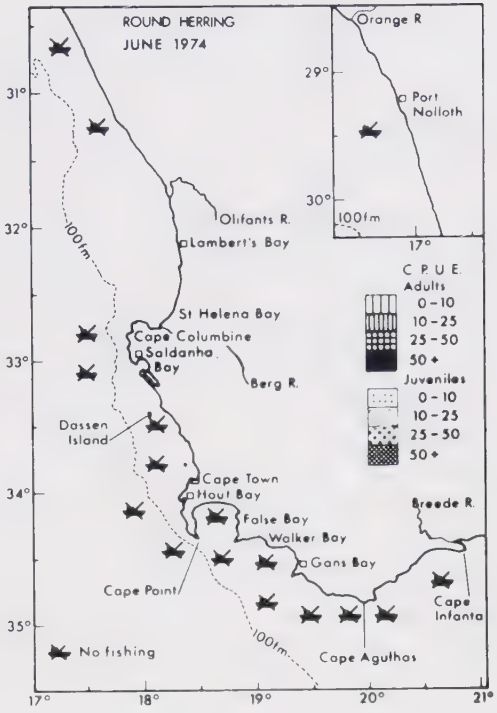
ROUND HERRING
JUNE 1974
Orange R
Port Nolloth
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Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E.
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17°
18°
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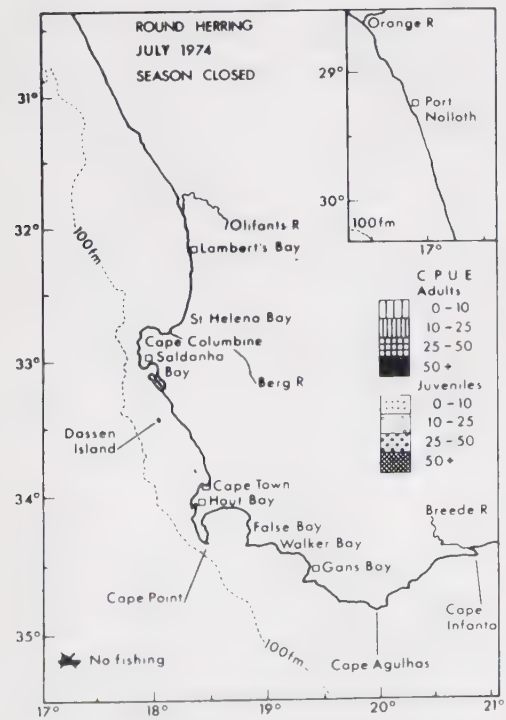
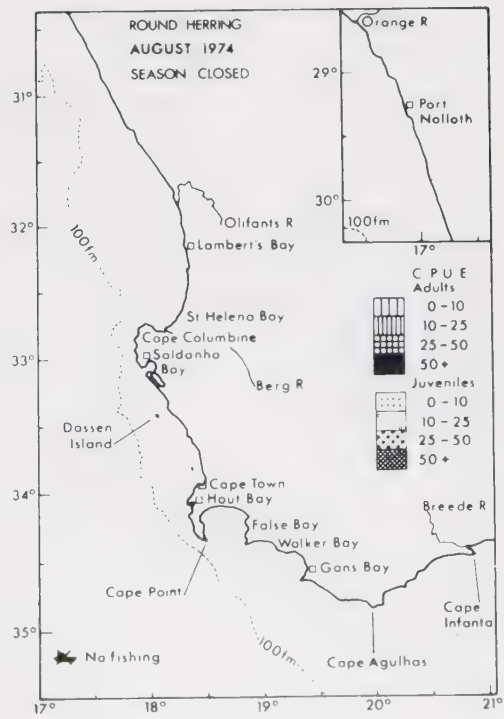

ROUND HERRING
JULY 1974
SEASON CLOSED
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17°
18°
19°
20°
21°


ROUND HERRING
AUGUST 1974
SEASON CLOSED
Orange R
Port Nolloth
29°
30°
100fm
17°
31°
32°
33°
34°
35°
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
25 - 50
50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17°
18°
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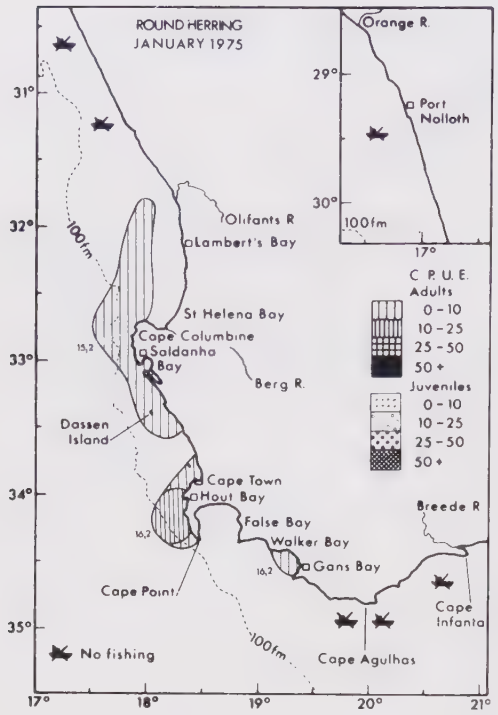
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Olifants R
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St Helena Bay
Cape Columbine
Saldanha Bay
Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Cape Point
Breede R
Cape Infanta
Cape Agulhas
100fm
No fishing
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Adults
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Juveniles
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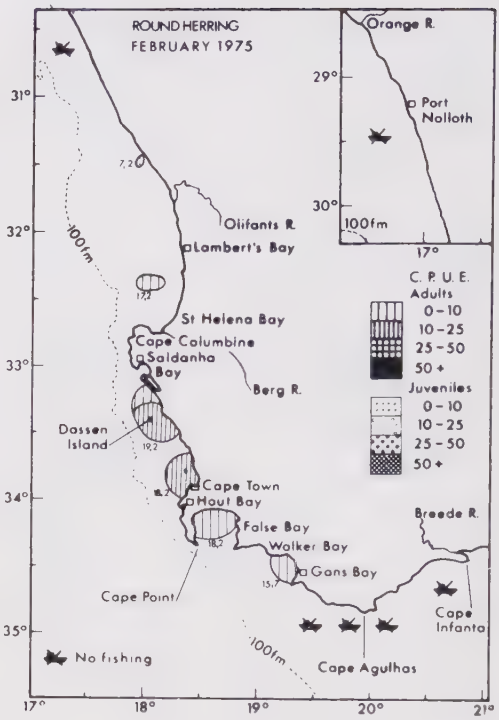
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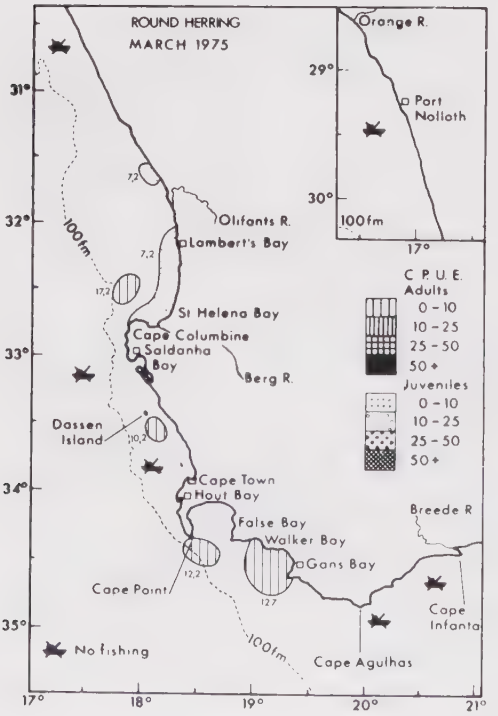
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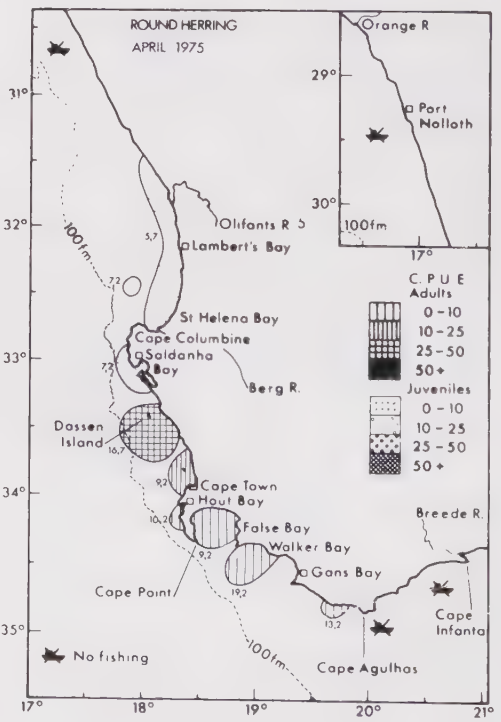
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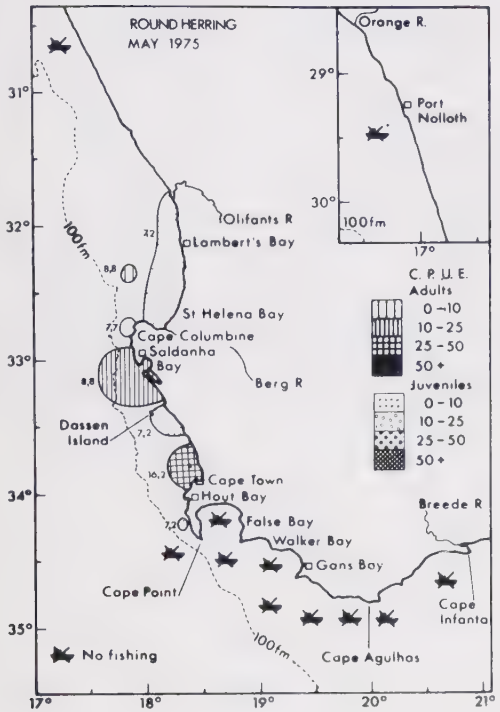
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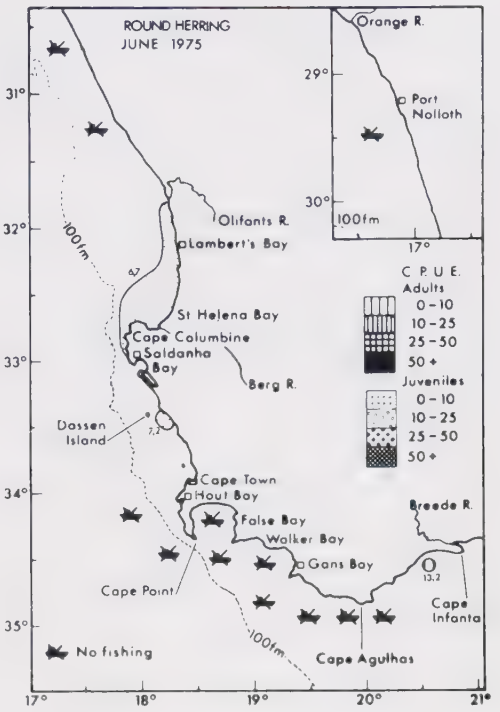
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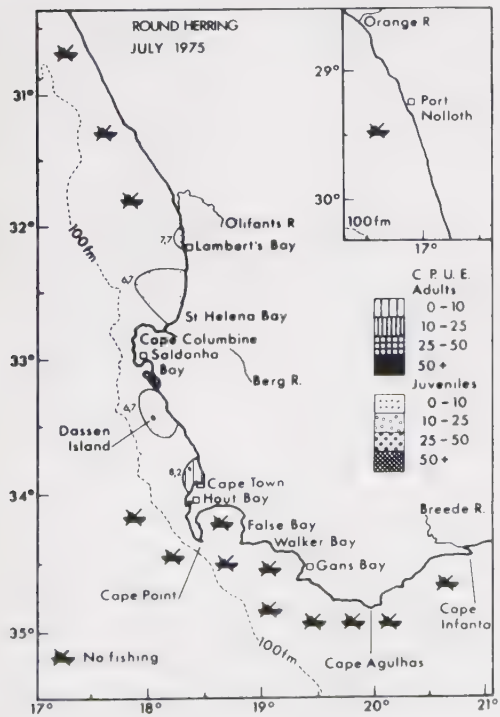
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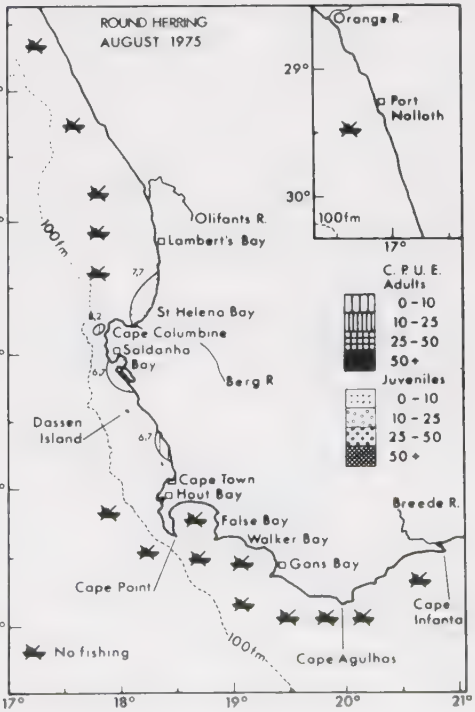
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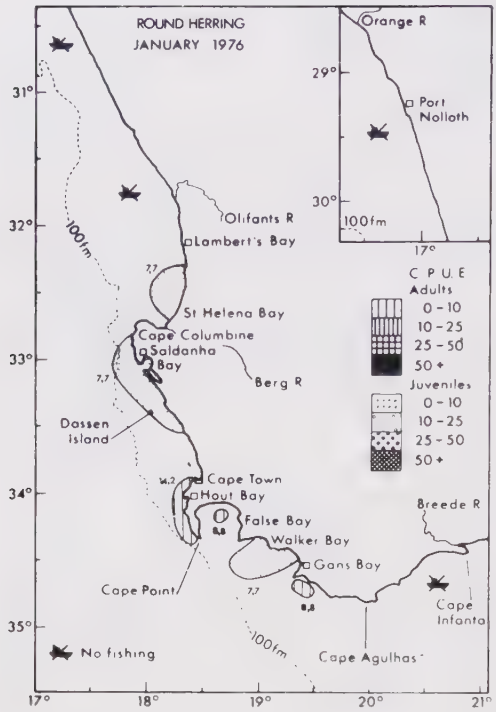
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JANUARY 1976
Orange R
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30°
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17°
31°
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33°
34°
35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
0 - 10
10 - 25
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50 +
Juveniles
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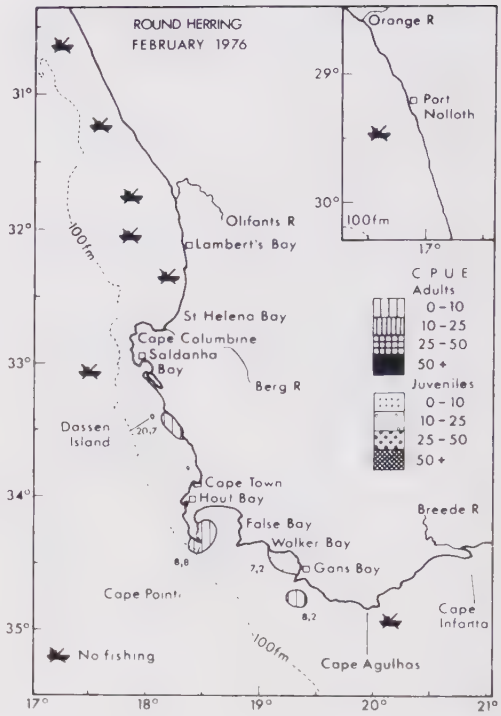
10 - 25
25 - 50
50 +
17°
18°
19°
20°
21°


ROUND HERRING
FEBRUARY 1976
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Port Nolloth
29°
30°
100fm
17°
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32°
33°
34°
35°
100fm
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
C P U E
Adults
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10 - 25
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50 +
Juveniles
0 - 10
10 - 25
25 - 50
50 +
17°
18°
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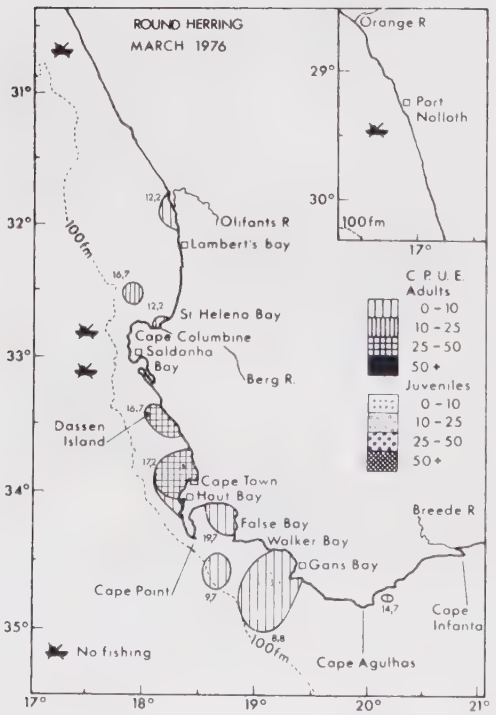
20°
21°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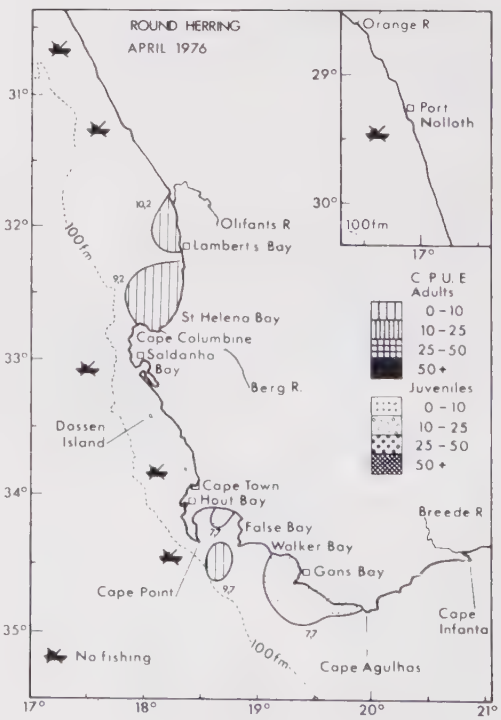
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No fishing
C P U E
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Juveniles
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25 - 50
50 +
17°
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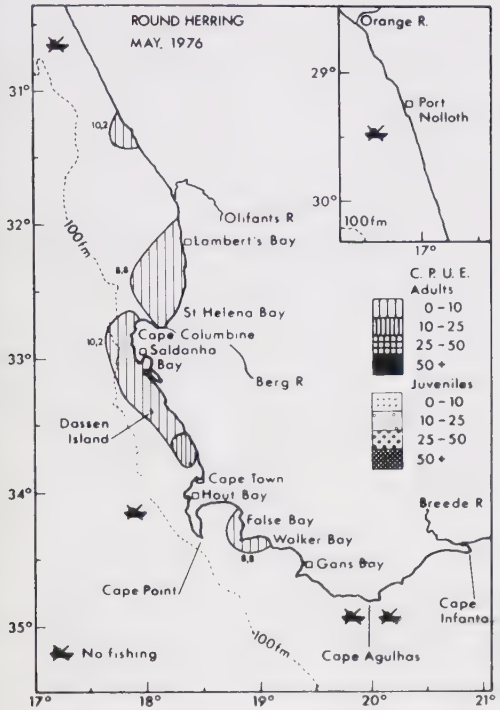
ROUND HERRING
MAY. 1976
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Port Nolloth
100fm
C. P. U. E.
Adults
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25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R
Lambert's Bay
St Helena Bay
Cape Columbine
Saldanha Bay
Berg R
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R
Cape Point
Cape Infanta
Cape Agulhas
No fishing
10,2
8,8
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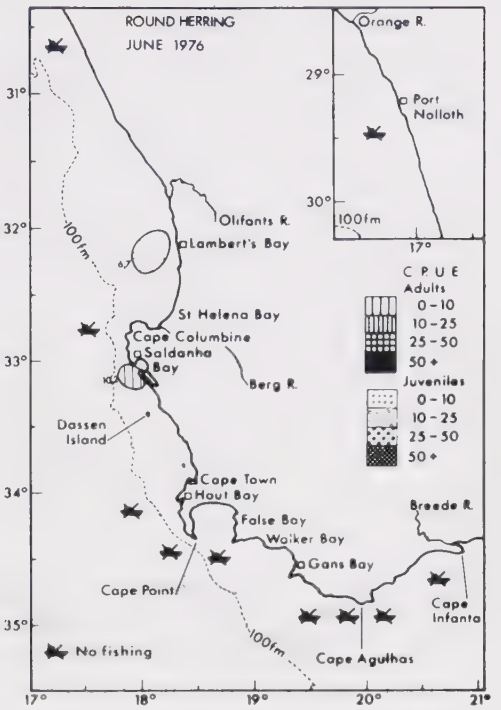
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Port Nolloth
100fm
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25 – 50
50 +
Juveniles
0 – 10
10 – 25
25 – 50
50 +
Olifants R.
Lambert's Bay
St Helena Bay
Cape Columbine
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Berg R.
Dassen Island
Cape Town
Hout Bay
False Bay
Walker Bay
Gans Bay
Breede R.
Cape Point
Cape Infanta
Cape Agulhas
No fishing
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29°
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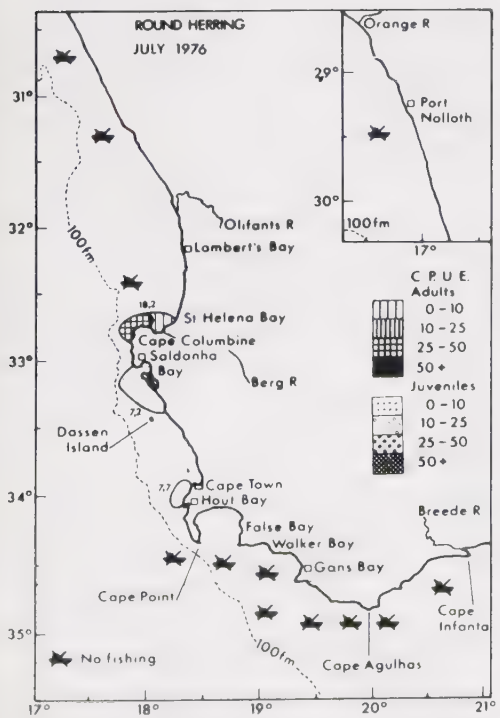
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Juveniles
0 – 10
10 – 25
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50 +
Olifants R
Lambert's Bay
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Saldanha Bay
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Dassen Island
Cape Town
Hout Bay
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Walker Bay
Gans Bay
Breede R
Cape Point
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Cape Agulhas
No fishing
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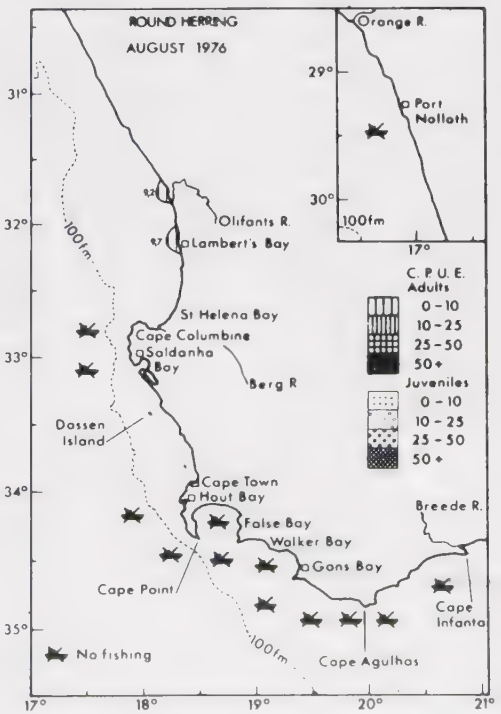
ROUND HERRING
AUGUST 1976
Orange R.
Port Nolloth
100fm
C. P. U. E.
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Juveniles
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10 – 25
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No fishing
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FISHERIES BULLETIN 14
1981
VISSERYE-BULLETIN 14

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